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Vegetation response to seismic lines: edge effects and on-line succession.

by

Arin Katherine MacFarlane ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Environmental Biology and Ecology

Department of Biological Sciences

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Faculty of Graduate Studies and Research

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Dr. S.A. Boutin

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Dr. V.J. Lieffers

Date: October 1, 2003

ABSTRACT

Seismic lines may influence aspen mixedwood forest vegetation structure and composition by 1) direct loss and change of vegetation due to the line itself and 2) changes in the adjacent forest edge vegetation structure and composition. Vegetation structure and plant community composition along seismic line edges were compared to paired interior forest samples. Understory plant community composition was compared between three ages of seismic lines to evaluate on-line succession, with particular attention to the presence and spread of non-native plant species. Edges adjacent to seismic lines had increased tree growth, recruitment, and vegetation cover, but tree mortality was unaffected. Understory plant community composition along seismic line edges was unaltered. However, the abundance of the most susceptible species was reduced at the edge. Understory plant community composition on seismic lines did not change over time to become more like interior forest. Several non-native plant species were established on seismic lines and were slowly spreading into the edge. Low impact seismic line techniques reduced changes to edge vegetation structure and composition relative to conventional seismic lines but did not speed recovery of on-line plant communities.

For my parents. Thank you for your high expectations and unwavering support.

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CHAPTER 1.
GENERAL INTRODUCTION TO CUMULATIVE EFFECTS IN NORTHERN ALBERTA AND THE ROLE OF SEIMSIC LINES

Cumulative effects and integrated landscape management

In the last 50 years the boreal mixedwood forest of northern Alberta has become increasingly disturbed by human activities. Timber harvesting is now considered to be the dominant disturbance in the mixedwood ecoregion (Crites 1999; Brumelis and Carleton 1988). However, oil and gas activity has already placed a significant footprint on the forested landscape. The area of land cleared for exploration and extraction of petroleum effectively doubles the amount of land logged each year (Alberta Environmental Protection 1998; Schneider 2002). Negative cumulative effects can result from this rapid expansion of industrial activities. Cumulative impacts can result from individually minor but collectively significant disturbances occurring over time and have the potential to compromise the forest's ecological integrity.

Research on the cumulative impact of forestry and oil and gas on boreal forest ecosystems is in its infancy. To date, research on the ecological impacts of industry in the boreal forest has been largely focused on the impacts of forestry (e.g. Veeman et al. 1999). However, during the Alberta Special Places process it was documented that the boreal forest had very few areas without human impact (Alberta Environmental Protection 1998). Most striking was the impact of oil and gas. The report states "while the forestry industry may supersede it in terms of its environmental impact, with respect to the entire boreal forest natural region the oil and gas industry has, arguably, left the most pervasive and intense "ecological footprint" of any human activity in the Region" (Alberta Environmental Protection 1998). Only 9% of townships (6 x 6 mile area) were without an oil and gas feature. However, this does not constitute a negative cumulative effect as a township with a single well or linear feature will still have habitat value. The majority of oil and gas disturbance was made up of linear disturbances (roads, pipelines, and seismic lines). These features not only cause reductions in habitat area but also increase isolation of fragments and increase the ratio of edge to interior habitat. Considering that large, unfragmented areas are considered necessary to maintain ecological integrity of many forests (Yahner 1998) the Alberta Environmental Protection report (1998) found that of the entire area in the boreal forest natural region only 13% could be considered intact, core habitat (defined as areas ≥10km^2). This was the first indication that cumulative industrial impacts in Alberta's boreal forest might have negative ecological consequences.

Negative economic consequences of cumulative industrial impacts are also an issue. Long-term accumulation of developments may lead to a reduction in the productive landbase and negatively impact timber supply (Lee and Timoney 2001). Schneider et al. (2003) demonstrated that the oil and gas industrial landscape footprint needed to be considered in the management of boreal forest natural resources or risk future sustainability.

Seismic lines: terminology and practices

In the six million hectare forest management agreement area of Alberta-Pacific Forest Industries (Al-Pac), as of 1997, there was an existing oil and gas footprint of approximately 98,000 ha (Al-Pac 2002). Currently, conventional oil and gas is being extracted faster than new supplies are being found and as reserves are exhausted there will be increased pressure to find and exploit remaining reserves (Alberta Energy and Utilities Board 1992). This will lead to increased disturbance of the forest over the next 20-30 years. However, Alberta's second-largest proven source of oil exists in the oil sands. Currently there are only three oil sand operations in northern Alberta yet a number of other companies have submitted plans to expand the industry in the future (Crandall and Prime 1998).

In oil and gas operations the largest proportion of forested land base cleared occurs during the exploration phase when searching for subsurface oil and gas reserves (Hardy Associates (1978) Ltd. 1981). Geophysical exploration involves generating seismic impulses by means of underground explosions. The impulses are reflected or refracted from subsurface geological strata, received by geophones and used to construct a model of the subsurface geology. To accomplish this a bulldozer first creates a linear clearing, a seismic line. Crews and equipment are then able to travel down one line to set charges (a source line) and position themselves down an additional line (a receiver line) to record the information. In Al-Pac's FMA geophysical exploration contributes 50% of the entire oil and gas footprint (Al-Pac 2002).

Current practices

Conventional seismic lines range in width from 6 to 9m and can be several kilometres long (Fig. 1.1). The horizontal spacing between individual lines varies with the level of geophysical information required and the nature of the subsurface structures. Heavy oil extraction requires much greater densities of lines than for extraction of conventional oil and gas reserves. A conventional program may have a few lines, parallel to each other, spaced 400m or more apart. In heavy oil extraction lines are in a grid pattern often spaced only 100m or less apart.

All trees and stumps on conventional seismic lines are removed using a bulldozer. This process may involve scraping of the topsoil as well as mixing of the topsoil with mineral soil layers. There are no specific requirements for reclamation of seismic lines besides erosion control through vegetation cover. Traditionally, sufficient vegetation cover was achieved through seeding of reclamation seed mixes that contain several species of agronomic grasses and legumes (Alberta Energy and Natural Resources 1979). Generally, seismic lines are intended to be cleared once and left to regenerate. However, of the seismic lines cleared each year approximately 30% of the total length is of existing seismic lines (Canadian Association of Geophysical Contractors unpublished data; see Appendix 1.1).

Recently, many seismic line companies have adopted the use of "low impact seismic" techniques (also referred to as LIS) (Government of Alberta 1999). The term LIS refers to a narrow line, 5m on average, that meanders through a stand attempting to avoid merchantable timber (Fig. 1.1). Low impact techniques also try to minimize disturbance to the soil and ground cover through low ground pressure bulldozers. However, low impact lines still require all trees and stumps to be removed from the line and therefore still cause soil disturbance. Use of low impact seismic results in increased exploration costs ($10-20/m drilled versus $5-7/m drilled for conventional lines) and slower speeds. Currently, only a restricted portion of the boreal forest (such as caribou zones) have government guidelines for the use of LIS and each company is able to negotiate the length of LIS in their seismic programs depending on the amount of merchantable timber (Government of Alberta 1999).

Other clearing methods can reduce the line width even further (Government of Alberta 1999). Specialized, narrow, equipment that can be used to clear 3-4m wide lines by mulching small diameter trees and shrubs and avoiding the merchantable timber. Drills are mounted on specially designed all-terrain vehicles and global positioning systems are used to locate the shot point. Where appearance of lines is a major issue heliportable operations create the narrowest lines by collecting the information using a combination of helicopter-carried equipment and hand-cut lines (1.5m wide; Fig. 1.1). Both techniques are even more costly than conventional lines ($40-50/m drilled), less available, and in the past exploration companies have very little incentive to use these techniques because they are not required by regulation in the boreal forest region (Cardell 2001).

Currently, the use of reduced width lines is only a small portion (less than 5%) of lines existing on the boreal landscape (Appendix 1.1). In the last 10 years the amount of LIS has increased substantially, effectively replacing conventional techniques. Only in most recent years (since 2000) have narrow (<3m) and hand-cut lines (<1.5m) been extensively used. Therefore, all comparisons will have to be made between conventional (6-8m wide) and low impact seismic lines (4-6m wide).

Landscape level impacts

The current length of seismic lines in Al-Pac's FMA is 68,506 km (Al-Pac 2002). Given conservative estimates of average line width, the total seismic footprint in Al-Pac's FMA is 34,253 ha. By comparison the combined area of pipelines and wellsites equals 29,440ha and the total area logged by Al-Pac since inception has been 47,071ha. The annual rate of logging by the oil and gas and forestry industries is nearly equal in Al-Pac's FMA (Schneider et al. 2003).

Seismic lines are one of the most dominant anthropogenic features in northern Alberta. High numbers of lines, extensive lengths, and a ubiquitous nature have seismic lines criss-crossing all areas of the boreal forest (Fig. 1.2). For example, one study area in northeastern Alberta with a seismic line density of $1.2km/km^2$ determined that 44% of the study area was within 250m of a seismic line (Dyer et al. 2001; Dyer et al. 2002).

Seismic lines can impact boreal forest plant communities primarily by 1) direct loss and change of vegetation due to creation of line itself and 2) changes in the adjacent forested edge vegetation structure and composition due to the creation of the line. If seismic line impacts are restricted to the line itself impacts will strictly be limited to the immediate footprint which, in the future, may be eliminated with best practices. If, however, there is a change in the adjacent forested edge the impact of seismic lines will be greatly magnified.

Because seismic lines are so pervasive, any additional impacts would have an effect disproportionate to their individual size. The current footprint is 34,253 ha, with a small edge effect (~5m) the area of influence doubles to 68,506 ha and the impact of seismic lines in the boreal forest, in terms of percent landbase impacted, could rival that of cut-blocks (Fig. 3). If the edge effect is even larger, the impact of seismic lines far surpasses that of any other disturbance type on the boreal landscape (Fig. 1.3) (Timoney and Lee 2001; Schneider 2002).

Edge effects on vegetation would have a large impact on the boreal landscape structure and composition, which may also affect processes such as propagule dispersal and animal behaviour (Murcia 1995). On-line and off-line changes in vegetation may result in loss or alteration of habitat for many additional boreal forest species. In order to characterize the total impact of seismic lines on a stand level as well as on a landscape level both types of impacts must be evaluated and accounted for in future conservation and management scenarios. Evaluating seismic line impacts on vegetation, on both the line itself and on the line edge, is the topic of this thesis.

Thesis overview

This thesis is organized into five chapters. Following this general introduction to cumulative effects and seismic lines (Chapter 1) is an extensive review of the mechanisms of edge effects with particular attention to mixedwood boreal forests (Chapter 2).

Chapter 3 compares vegetation structure along the edge and interior of seismic lines. My objectives were:

A. To determine if there is an edge effect along seismic lines. Tree mortality, growth, and recruitment along with vertical shrubby cover were the primary variables examined because changes in these structure variables indicate the primary mechanisms by which other community changes may occur.

B. To compare conventional seismic clearing techniques with more recent low impact seismic clearing techniques to determine if edge effects can be diminished with changes in industrial practices.

Chapter 4 examines the composition of the plant community on seismic lines and in adjacent forests over time. My objectives were:

A. To determine if succession occurs on seismic lines.

B. To determine if seismic lines influence the plant composition of adjacent forest edges.

C. To determine if non-native species have established in on-line plant communities and if they have spread into the adjacent forest.

D. To compare conventional seismic clearing techniques with more recent low impact seismic clearing techniques to determine if any changes to plant communities on-line or along the edge can be diminished with changes in industrial practices.

Chapter 5 presents general conclusions and evaluates landscape level implications of changes in on-line and edge vegetation. Both ecological changes and economic impacts of the cumulative effects of seismic lines are discussed.

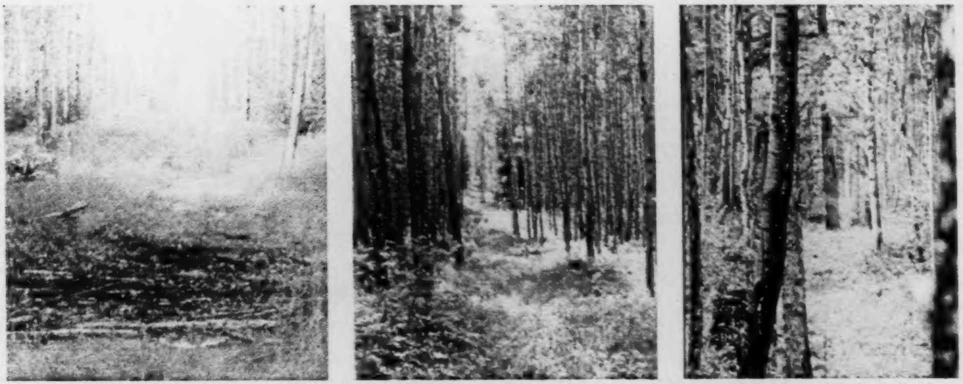


Figure 1.1 Three types of seismic lines cut in the boreal forest region. From left to right: conventional (straight, 6-8m wide), low impact (meandering, 4-5m wide), and hand-cut (avoids trees, <1.5m wide).

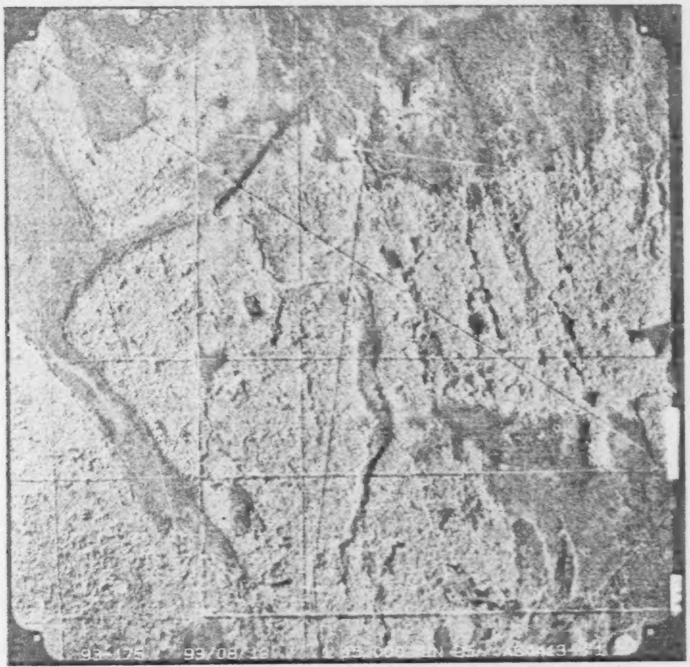
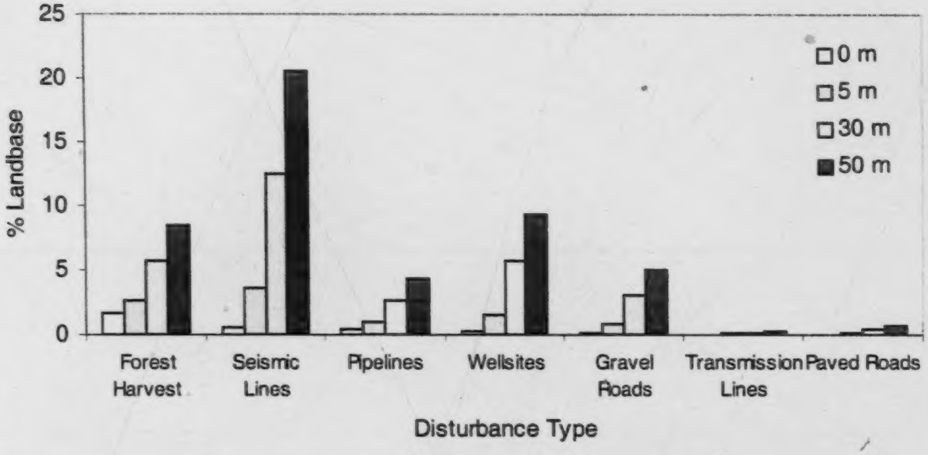


Figure 1.2. Aerial photograph of a portion of township 71 range 23 west of the 4th meridian. Dark grey lines are conventional seismic lines. The picture covers a 3.6 by 3.6 km area.



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CHAPTER 2.
THE POTENTIAL FOR EDGE EFFECTS ON SEISMIC LINES: IMPLICATIONS FOR VEGETATON STRUCTURE AND COMPOSITION

Introduction

Forest fragmentation is the process of subdividing a continuous habitat type into smaller patches, which results in the loss of original habitat, reduction in patch size and increasing isolation of patches (Andren 1994). In forested ecosystems, fragmentation is considered one of the primary causes of species extinction (Wilcox and Murphy 1985). Depending on the severity of the fragmentation process and sensitivity of the ecosystem affected, native plants, animals, and natural ecosystem processes may be compromised or fundamentally altered. One mechanism leading to altered ecosystem dynamics is the interaction of the remaining forest patches with the surrounding altered area. This interaction is termed 'edge effects' (Saunders et al. 1991).

Edge effects can be considered to be the influence exerted by an opening (or differing cover type) on the ecological processes and attributes of an adjacent forest. There are three types of edge effects (Murcia 1995): 1) abiotic effects, involving changes in the environmental conditions that result from nearness to the adjacent opening; 2) direct biological effects, which involve changes in the abundance and distribution of species caused by changes in the environmental conditions near the edge and determined by the physiological tolerances of species to the conditions on and near the edge; and 3) indirect biological effects, which involve changes in species interactions, such as predation, pollination, and seed dispersal.

Seismic lines produce large amounts of linear edge and likely alter the physical conditions at the interface between the seismic line and adjacent forest. Edge effects have primarily been measured on the edges of agricultural fields (e.g. Ranney et al. 1981; Fox et al. 1997) or clearcuts (e.g. Chen et al. 1992) in temperate and tropical forests. Edge effects have not been quantified on narrow, linear disturbances such as seismic lines and very few edge effect studies have been conducted in boreal forests. This review examines the potential for direct biological effects along seismic line edges within aspen mixedwood boreal forest. Specifically, I will examine the mechanisms that may lead to potential changes in vegetation structure and composition. Implications of edge effects will be discussed in terms of indirect biological edge effects.

Direct edge effects

Potential effects of increased wind

Increased tree mortality is often associated with the creation of an edge (Murcia 1995). There may be several explanations for this mortality such as stress induced mortality due to increased moisture demand from greater evapotranspiration (e.g. Ranney et al. 1981; Kapos 1989) or sudden exposure to light (Laurance et al. 1998a) and/or increased wind (Chen et al. 1992; Laurance et al. 1998a; Burton 2001). Wind is suspected to be the main reason for mortality at newly created or young edges in boreal forests (Burton 2001; Harper and MacDonald 2002). Harper and MacDonald (2002) hypothesized that due to aspen's shade-intolerant nature they would not be susceptible to mortality due to increases in light, rather mortality would be due to changes in wind at the cutblock edge. In boreal forests windthrow events on edges are likely related to wind climate, growth form, and the size of adjacent opening (Burton 2001).

In the northeast boreal forest winds can reach speeds that will cause windthrow and windbreak. Gusts, in particular, are responsible for tree damage. Wind gusts are generally westerly with some northwesterly. Wind gusts regularly reach up to 70-90 km/hr, with rare extreme guests up to 130km (Flesch and Wilson 1993). Wind gusts may cause a tree to sway past its maximum capability causing windthrow. Windbreak results as gusts push the tree in the direction opposite to its natural direction of sway. Seismic line edges may contribute to increased break or windthrow as trees usually accustomed to support from neighbouring trees during periods of sway no longer have neighbours to lean on and swaying amplitude may increase (Navritil 1995).

A linear forested edge may also contribute to increased mortality by altering the normal pattern of wind flow over the forest canopy. When a wind current hits an edge, it is deflected upwards and strikes more swiftly moving currents in the air layers above the stand canopy creating turbulence (Navritil 1995). Eddies resulting from this turbulence are very effective at transferring energy onto standing trees. Individual trees are destabilized and may break or blow down. It is generally accepted that windthrow is more a result of turbulence than by pure wind velocity (Navritil 1995).

Individual characteristics of trees influence susceptibility to wind damage. For example trees with a higher height to diameter ratio are considered more susceptible to wind damage (Navritil 1995; Burton 2001; Harper and MacDonald 2002). A low height to diameter ratio may indicate a larger crown, lower centre of gravity, and a better root system, which is why trees with large ratios are more likely to break. Tall trees are also more susceptible to windthrow because wind speed is higher at increased distance from the ground. Trees that have deeper more well developed roots can support a heavier crown and more wind force. Aspen trees may not be particularly susceptible to wind damage as they have large, flexible canopies, do not reach tall tree heights and are deeply rooted (Navritil 1995). In contrast, spruce trees are generally considered to be more at risk than aspen for windfall since they have large canopies and shallow root systems.

Site conditions also influence susceptibility to wind damage. Trees grown in open stands are more windfirm because they benefit from wind stimulation. Increased vigour resulting from adequate sunlight during development also improves the height-diameter ratio and thus wind stability. Largely open, aspen mixedwood stands also have reduced susceptibility due to their ability to break up airflow due to their irregular mixture of species and structure. For example, the coniferous component, which is generally less wind firm, may contribute to the overall wind firmness of the stand by slowing the wind velocity at the edge due to their well developed lateral canopy.

It is questionable whether forested edges of seismic lines will suffer extensive wind damage. If wind damage on edges is most related to wind, species and site types, and the size of adjacent opening (Burton 2001) then aspen mixedwood stands along seismic lines are unlikely to be prone to wind damage. However, initially after clearing individual trees will be destabilized and is possible that only the most susceptible trees may break or blow down. Following this initial period of potential damage stability will improve.

Potential effects of increased light

Light can be said to have a universal role in increasing productivity on a forested edge. This productivity is manifested in different ways for different systems: through rapid growth of shrubs (Matlack 1993), development of a dense herbaceous understory (Ranney et al. 1981), invasion of non-native plants (Brothers and Spingarn 1992), shifts in community composition (Fraver 1994), germination and growth of seedlings (Chen et al.1992; Burton 2002), or, as in the boreal forest, suckering and growth of young trees (Harper and MacDonald 2002).

Newly created edge may not have as great an effect on species within aspen mixedwood stands due to relatively high within stand heterogeneity in canopy cover. Aspen canopies are not as dense as coniferous forests, for example, resulting in stands that are patchy, with substantial variation in the amount of sunlight reaching the understory (Constabel and Lieffers 1996). As aspen stands age light increases linearly (Lieffers and Stadt 1994). Species within these stands may be adapted to relatively high light availability so that they are generally unresponsive to the creation of an abrupt edge. However, light varies by understory height position with most of the available light intercepted by the taller shrub and saplings before it ever reaches the herbaceous or ground layers (Constabel and Lieffers 1996). A vertical opening, such as an edge, may increase light to all understory strata, creating light availability patterns that are uncommon in aspen stands. Species responses to increased light may vary, with either positive or negative responses in cover (Fraver 1994; Harper 1999).

Edge type will affect the magnitude of change in microclimate and the longevity of any vegetation changes. For example, aspen dominated cutblocks are predicted to have initially strong but short-lived edge effects as the rapid regeneration in the adjacent cutblock forms the equivalent of a side canopy, further blocking changes in wind and light. Edges of narrow seismic lines are difficult to compare to edges of large cutblocks. Due to both species adaptations to the heterogeneous light environment of aspen forest and the narrow nature of seismic lines, it is likely that any edge effects will be generally smaller than those recorded on the edges of cutblocks.

Seismic lines are much more similar to the silvicultural technique of strip-cutting. Groot et al. (1997) found increased light levels on edges of 9m wide strip cuts in 40 year-old aspen forests. Light levels increased (30% higher) from the centre of the opening to the north edge and then declined (45% lower) from the north edge after only 5m into the adjacent forest. In older, less dense, forests this light gradient might be less pronounced as more light filters through the canopy. Kabzems (2001) found in 150 year-old aspen-spruce mixedwood stands, albeit in larger gaps, that light transmission reached maximum intensity 5m away from the adjacent forest edge. At the edge, light levels dropped from the maximum intensity recorded in the gap by 4%. Once inside the forest, light levels dropped rapidly. 5m into the forest there was a 15% reduction in light and 10m from the edge the light dropped by an additional 22%, to a level that was equivalent to the interior forest. These studies indicate that light levels will be elevated in forest adjacent to a seismic line but that light will diminish over small distances deeper into the forest.

Changes in light at the edge of strip cuts resulted in changes to the vegetation on the edges. Height and diameter growth of planted spruce seedlings were directly correlated to the amount of sunlight reaching the strip-cut opening and the adjacent south-facing edge (Groot et al. 1997). Growth of seedlings was elevated relative to the interior forest for a distance of 3m into the adjacent edge. However, relative to seedling growth in the clearing, height and diameter increases in that 3m were unsubstantial. Typically, for the understory strata, a peak in cover occurred at the very interface between the forest and the strip-cut where the sunlight was at its maximum and declined exponentially once inside the forest. However, understory species less than 75cm in height reached maximum cover 3m into the forest edge and subsequently declined.

Conventional seismic lines have been shown to have edge effects due to increased light. Revel et al. (1984) studied seismic lines in Alberta's foothills and found that understory plant communities and tree growth on edges differed from interior forests. Edges had increased abundance of saplings, which was due to a combination of conifer and deciduous saplings. This was surprising because deciduous species were relatively uncommon in the forest type studied. In comparison to the interior forest there was also increased diversity of shrubs and herbs on the edge. A strong indicator of changes in light and humidity on the edge was a significant decrease in the cover of mosses relative to the interior forest. In foothills forests, the magnitude of change in understory microclimate from a closed coniferous canopy to an open seismic line would be much larger than the expected change in an aspen forest.

Increased light on the edge may affect canopy trees of forests adjacent to seismic lines. Revel et al. (1984) and Bella (1986) reported increases in growth rates of the dominant conifer species along seismic lines. Lodgepole pine, white spruce, and black spruce growing within half a tree height from the line (~10m) experienced a 20-40% increase in radial growth. Bella (1986) was unable to detect increases in aspen growth directly due to the creation of the seismic line. Instead of radial growth, aspen may expend energy resources in producing suckers (Peterson and Peterson 1992). However, understory conifer may put on considerable growth if "released" from the overstory shade (Yang 1991).

Invasion of non-native species

Conservationists have been concerned that edge effects will result in reductions in remaining patch size of forest fragments due to structural changes. Simultaneously, they have asked whether micro-environmental changes caused by creation of edges has led to shift in species composition at forest margins. This work has emphasized loss native forest species rather than introduction of non-native species, however forest patches are often surrounded by many potential invaders. Extensive networks of seismic lines could encourage spread of non-native species through edge effects by changing the biotic conditions at the edge creating an environment more amenable to species that like disturbed, open areas.

Specific properties of the edge microclimate that could predispose it to an invasion include increases in: light and soil temperature (Brothers and Spingarn 1994) that then leads to increased decomposition and nutrient availability, atmospheric deposition of water and nutrients on edges (Weathers et al. 2001), tree uprooting provides more germination sites free of competition (Esseen 1994), and increased propagule pressure as seeds are carried further into the interior forest by wind through the exposed edge (Cadenasso and Picket 2001). Studies conducted on agricultural edges routinely find invasive non-native species, however penetration distance varies: 2m (Brothers and Spingarn 1994), 5m (Gelhausen et al. 2000), 10m (Burke and Nol 1998). Clearcut edges do not seem to have non-native species invading (Euskirchen et al. 2001; Harper and MacDonald 2002). However, the difference between young (clearcut) and older (agricultural) edges may make a big difference in the rate of spread and establishment of non-native species. Also, in the case of agriculture-forest edges, close proximity to non-native species seed sources may speed the invasion process.

Seismic lines may be corridors for dispersal, provide suitable habitat, and contain reservoirs of propagules for future invasion episodes (Parendes and Jones 2000). On seismic lines non-native species may be brought on equipment or personnel indirectly, but may also be directly seeded onto cleared areas within seed mixes used to control erosion or facilitate reclamation. Lines that are compacted or have much of the organic soil removed may be susceptible to weeds that are wasteland specialists (e.g. *Crepis tectorum*) or just hardy competitors (e.g. *Cirsium arvense* and *Taraxacum officinale*). Once established, abiotic factors (wind and water) as well as animal movement may distribute weeds or non-natives into communities along the line and into the surrounding forest. Changes in light, soil and air temperature, and humidity may allow non-native species to persist once they have been transported to the adjacent forest.

Revel et al. (1984) reported that the composition of regenerating plant communities on seismic lines were altered from the pre-existing community by the changes in microclimate as well as introduction of seeded plant species. Non-native species had spread up to 5m into the adjacent forest over a 10 to 16 year period but did not seem to dominate or replace the native community. Transmission corridors in New York State, similar in form and function to seismic lines, had relatively high occurrence of non-native species indicating their susceptibility to colonization by non-native plants. A small component of these species had also spread into the surrounding forest (Cameron et al. 1997). The authors hypothesized that the non-native species were maintained on the transmission line due to re-disturbance by maintenance and recreational activities.

Changes in the amount and rate of industrial and natural disturbances may create opportunities for non-native species invasion off seismic lines into the broader landscape. In particular, interactions between different disturbances may have synergistic effects that increase the spread of non-native plant species (Hobbs and Huenneke 1992). For example, non-native species invasion into forests in Ontario may have been facilitated by an increased ratio of forest edge to interior (Burke and Nol 1998). Anthropogenic disturbance in Alberta's boreal forest is relatively recent and the rate of non-native species invasion may increase in the future.

Indirect edge effects

Alterations to the vegetative community can modify the composition and behaviour of fauna, depending on the degree of contrast in vegetation structure and composition at the edge (Yahner 1988; Noss and Cooperider 1994). It is recognized that edge effects can greatly diminish the area of high-quality interior forest habitat, which is a concern for species and processes that require intact older forests or that are dependent on forest interiors (Yahner 1988). Since seismic lines are so ubiquitous, a small edge effect greatly increases landscape footprint, thereby greatly increasing the fragmentation of Alberta's boreal forests.

Increases in tree mortality can alter the composition and amount of dead wood resources, which are a critical resource for forest biota (Harmon et al. 1986). Standing dead trees (snags) provide habitat for numerous wood boring insects (Neimela 1997) and foraging sites for birds. Snags become nesting sites for cavity-nesting birds (Erskine 1977), squirrels (McDonald 1995) and bats (Barclay et al. 1988). Downed woody material (DWM) supports a variety of fungi, mosses, lichens, herbaceous vascular plants and woody vascular plants throughout its decay (Soderstrom 1988; Crites 1995). DWM is also important to invertebrate and vertebrate animals for body temperature regulation and access to food, cover, and transportation corridors (Harmon et al. 1986).

Dispersal and foraging activity of both invertebrate and vertebrate animals may be influenced by the change in microclimate and vegetation structure at the edge. Species richness of arthropods has been show to increase at edges (Helle and Muona 1985; Spence et al. 1996; Neimela 1997). Structurally dense vegetation, with high density of arthropods, provided cover and forage for birds during nesting and feeding resulting in a greater number of nests within 15m of edges (Gates and Gysel 1978). Hansson (1994) found several rodent and songbird species were at highest abundance along clearcut edges in northern Sweden. Relative abundance and diversity of small mammals was greater within 10m of clear-cut edges in the forests of New Brunswick (Sekgororoane and Dilworth 1995). Alternatively, high temperatures and lower humidity may cause desiccation of the leaf litter thereby reducing abundance of potential prey for ground-foraging songbirds (Burke and Nol 1998; Van Wilgenburg 2001). Wildlife populations can also decrease in number and diversity as edge vegetation is altered (Lovejoy et al. 1986).

Increases in avian nest predation and parasitism have been associated with expansion of edge habitat in temperate forests (Brittingham and Temple 1983; Wilcove et al. 1986). Yet, in the boreal forest, there is little to no evidence that edges contribute to songbird predation risk (Song and Hannon 1999; Ibarsabal and Desrochers 2001). Songbirds may not perceive any differences in vegetation structure between the edge and interior due to inherently high heterogeneity.

However, if structure (i.e. shrub cover) does increase on seismic line edges and individuals chose to nest in this favourable habitat, the ease of travel and relative security of a seismic line may increase encounter rate by more traditional predators (Andren 1995) rather than inviting heavy pressure from more generalist predators.

Conclusion

Studies on the impacts of edge on forest structure and composition have largely focused on edge next to agricultural fields or clearcuts, justifiably as these human-origin features dominate landscapes worldwide. However, in the forested areas of Alberta this is not the case. Seismic lines are one of the most pervasive and intense ecological footprints of any human activity in the boreal region (Alberta Environmental Protection 1998). Due to the long lengths of seismic lines and their pervasive nature any additional edge effect would greatly magnify their impact. I argue there it is reasonable to hypothesize that seismic lines may cause changes in adjacent edge structure and composition. Therefore, it is relevant and necessary to examine seismic lines for any vegetation edge effects so that we can then evaluate current management strategies to best conserve the ecological function and biodiversity of the boreal forest.

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CHAPTER 3:
CHANGES IN FOREST STRUCTURE ALONG CONVENTIONAL AND LOW IMPACT SEISMIC LINE EDGES IN BOREAL MIXEDWOOD FOREST

Introduction

In Alberta, oil and gas exploration, extraction and transport has resulted in continuous clearing of forest since the 1950s. The loss of forested area is a concern for maintenance of biodiversity as fragmented forest may not function in the same capacity as continuous forest (Saunders et al. 1991). Smaller patches of remaining forest result in more edge habitat which may further compromise the ecological integrity of remaining forest patches by reducing the effective habitat area of the patch. Influence from the adjacent non-forest may alter the structure and composition of the surrounding forest by changing processes at the edge.

Edges are subjected to microclimate characteristics that differ markedly from those that typify the forest interior (Chen et al. 1995) resulting in a unique interface between the forest and the clearing. There are three possible key impacts of anthropogenic edge on boreal forest vegetation. Firstly, due to increased exposure to wind there may be increased tree mortality. Secondly, due to the openness of the adjacent non-forest and possible canopy openness, irradiance may increase and result in increased vegetation growth and recruitment. Finally, as edge biotic and abiotic processes are altered plant community composition may change. The potential negative effects of adjacent openings on forests are widely appreciated among conservation biologists (Murcia 1995). However, edge effects may be significant from a purely economic perspective if they also result in a reduction in harvestable tree volume.

There is a paucity of information regarding edge effects in *Populus*-dominated forests of the boreal mixedwood region. However, in this region, research on riparian edges and on clearcut edges have indicated that edge effects do occur (Harper and MacDonald 2001; Harper and MacDonald 2002). Generally, edge effects in the boreal mixedwood are much weaker than edge effects reported in regions dominated by conifer forests (Chen et al. 1992; Burton

2002). Lakeshore edge forests were structurally more diverse and had more tree recruitment up to 40m into the edge forest as compared to interior forest (Harper and MacDonald 2001). Within 20m of cut-block edges, and for at least 16 years after logging, there was increased tree mortality and snag breakage resulting in increased downed woody material (DWM). Edges experienced rapid regeneration of *Populus* with a corresponding decrease in shrub cover and these effects were still detectable after 16 years (Harper and MacDonald 2002). Both studies indicated that rapid regeneration of young trees, both on the edge and in the adjacent opening, greatly diminished microclimate changes penetrating the edge, much like the development of a side canopy at agricultural edges (Williams-Linera 1990; Matlack 1993, 1994).

Presently, seismic lines are much more pervasive across Alberta's boreal landscape than forestry cutblocks yet much of what is known about edge effects comes from cutblock edges. Conventional seismic lines are created by clearing long, 8m wide, linear corridors through continuous forest. The energy sector clears an average of 550 ha annually for seismic lines within Alberta-Pacific Forest Industries'(Al-Pac) Forest Management Agreement area (Appendix 1.1). Approximately 40% can be considered merchantable land base. Since none of the trees cut are salvaged, seismic lines are generally additive to the area logged by forest companies. Recently, many seismic line companies have adopted the use of "low impact seismic" techniques (LIS) to minimize the forested area cleared (Government of Alberta 1999). The term LIS refers to a narrow line, 5m wide on average, that meanders through a stand attempting to avoid merchantable timber while still maintaining a fairly constant bearing. Low impact techniques also try to minimize disturbance to the soil and ground cover through low ground pressure vehicles. Regardless of width, the high numbers of lines, extensive lengths, and ubiquitous nature have resulted in extensive amounts of linear edge in the boreal forest of Alberta. Even small amounts of edge effects along seismic lines would result in a greater expansion of the seismic line impact. For example, an increase in tree mortality for only 5m along the seismic line edges would double the area impacted by seismic lines, far surpassing the total area logged.

This research was undertaken to examine the impacts of seismic line clearing on adjacent boreal aspen mixedwood forest structure because changes in forest structure indicate the primary mechanisms by which other community changes may occur. Specifically, I measured the effects of seismic line clearing on forest edge structure as measured by: 1) mortality of canopy trees, 2) growth of canopy trees, 3) and density of regenerating trees. I predict that, initially, edge trees exposed to increased wind will result in an increase in tree mortality, detectable by examining standing tree density, number of standing dead trees, and amount of recently fallen trees. Edge canopy trees are expected to increase in yearly growth as a result of increased light on the seismic line edge. Increased light will also stimulate sapling regeneration, through clonal suckering, on the edge. However, I do not expect these effects to extend very far into the surrounding forest due to the narrow width of the seismic lines. Hence, by creating narrower lines edge effects may eliminated entirely. To test this assumption narrower seismic lines, 4-5m wide, termed low impact lines (LIS), were sampled and compared to the conventional seismic lines to determine if changes in industrial practices might mitigate seismic line edge effects.

Study area

Research was conducted in the central mixedwood subregion within the boreal forest region of Alberta (Alberta Environmental Protection 1994). This subregion falls within the western boreal plains ecozone (Ecological Stratification Working Group 1995). The study region has a boreal climate with mean summer temperatures at 13.5°C and mean winter temperature at –13.2°C. Annual precipitation is 397mm, occurring mostly in the summer. Gray Luvisol soils predominate on undulating morainal plains with gleysols on wetter sites and some Eutric Brunisol soils on more xeric sites (Alberta Environmental Protection 1994). The study area encompassed three forest management units in northeastern Alberta; L1, L2 and S7. Sites were closest to the communities of Lac La Biche (55°45'N, 112'00W, ~580 m above sea level), Calling Lake (55°N, 114°W, ~640m above sea level) and, Athabasca (54°43'N, 113°17'W, ~560m above sea level), respectively (Fig. 3.1).

Sample site selection

Thirty aspen dominated mixedwood stands adjacent to conventional lines and thirty-one stands adjacent to low impact seismic lines were examined for edge effects (Appendix 3.1). Conventional lines (~8m wide) that were about 10 years of age (ranged from 8 –13 years old) were chosen for this study as they were reasonably abundant, were not re-cleared as commonly as older lines, and were likely old enough to have developed edge effects. In contrast to these lines, narrower "low impact" seismic lines (~5m wide) were 5 to 8 years old because this practice was only recently implemented.

Conventional seismic lines were dated using two methods. Lines older than 1993 that did not have accurate digital records were aged using aerial photographs and dated to the year in which they first appeared in the photograph. Conventional lines created after 1993 and that had accurate attribute data were chosen using digital files. Low impact seismic lines, created between 1993 and 1997, were chosen using non-digital seismic program maps submitted to Alberta-Pacific Forest Industries, the forest management agreement (FMA) holder in this region. Lines that had been widened or converted to a road or pipeline were rejected from the study after field reconnaissance.

Each selected seismic line was sampled from one to three times at individual stands along the length of the line, thereby having a unique stand/line combination for each replicate site. Sites were a minimum of 400m apart along a seismic line. Stands were selected a priori to intersect the study lines using a GIS and Alberta Vegetation Inventory (AVI) data. Sample stands were dominated by aspen (*Populus tremuloides*) (>50% of canopy). Secondary species included balsam poplar (*P. balsalmifera*), white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*) in either co-dominant or sub-dominant canopy positions. Site characteristics were typical of low-bush cranberry aspen stands in northern Alberta (Beckingham and Archibald 1996), being well drained on level to gently sloping terrain (<15% slope) with an understory most frequently dominated by *Rosa acicularis*, *Viburnam edule*, and *Epilobium angustifolium*. Each stand was of fire origin, initiated between 1900 and 1940. Selected stands were a minimum of 33ha in size to completely encompass the seismic line width and a 50m buffer surrounding the sampled area – 300 m long and 110m wide. Each stand was treated as a single replicate with an edge and interior subsample.

Each site was sampled in the adjacent forest on the side of the line that received the maximum amount of sunlight to determine what the maximum potential edge effect would be. If a line was oriented north-south then the samples were placed to the east of the line, if the line was east-west then the samples were placed to the north. If the line was oriented diagonally then the angle determined the positioning of the plots. If greater than 45^{o} from north then plots were placed to the north of the line and if less than 45^{o} from north then they were placed to the east of the line. Out of the 30 conventional sites, 19 were sampled on lines oriented east-west, 9 were oriented north-south, and only 2 were northeast diagonal seismic lines (Appendix 3.1). Out of the 31 low impact sites, 16 were oriented east-west, 9 north-south, and 6 diagonally (Appendix 3.1).

Sampling at each site

At each, I sampled paired plots placed 2.5m and 60m from the seismic line edge into the interior forest, with the long axis of the plot parallel to the orientation of the line (Fig. 3.2). The samples were placed 2.5m within the adjacent forest for two reasons. First, the edge of the forest was defined as the most continuous line of tree trunks bordering the seismic line clearing but over the distance of our plot (200m) the seismic line edge would have wandered causing our samples to encompass parts of the line clearing. Line and edge regrowth also made it difficult to distinguish the line from the adjacent forest when standing in the forest. By placing it 2.5m in from the edge I was confident that the entire plot would always be within the adjacent forest edge. Second, conventional clearing methods require that felled trees be pushed to either edge of the cleared portion of the line, creating slash piles. Plot placement avoided these slash piles (especially important for down woody material) and also avoided the damage caused by the machinery to the edge trees as the piles were formed. On meandering low line impact seismic lines, the samples were placed 2.5m into the forest, measured from the concave curved portion, which penetrated the sampled side of the line to further avoid the line clearing as the edge meandered.

A minimum distance of 50m was chosen as a buffer from all additional clearings because most studies on edge effects conducted in either deciduous dominated or boreal forests have found that changes in structure variables were within 50m of the edge (Matlack 1993, 1994). In the aspen mixedwood forests of northeast Alberta cut-block edges had changes in forest structure up to a maximum distance of 60m, with the majority of effects being restricted to within 20m (Harper and MacDonald 2002). Additionally, the areas sampled in this study had many additional disturbances and sample size would have been much reduced if buffer sizes were increased.

Determination of sample sizes

Due to the inherent spatial variation of forest structure, sampling of each structural element was preceded by analysis to determine the optimum sample size to capture a robust estimation of the population mean and variance. Plot size and sampling intensity was determined using preliminary data manipulated using a Monte Carlo simulation of continuous random sampling with replacement. Sample area was artificially increased by randomly compiling data from all plots for trees, snags, and downed woody material. This exercise was an effort to determine the optimum size of the plot that would consistently capture a representative amount of variation for each site. The simulation was run for 1000 iterations and the mean, variance, and mean/variance ratio of the different sample sizes plotted to determine at which plot size the values reached an asymptote. The mean and standard deviation generated from the simulation of that particular plot size was then used in a power analysis, specifically designed for use with data collected for a paired t-test, to determine, at $B = 0.8$, which total sample size would be able to detect a 1% change per year (10% maximum) in the response variables (Erdfelder et al. 1996).

Initial Monte Carlo simulations on snag density indicated that a plot size of 4000m^2 would be optimal for each site. However this was very large and its size would eliminate many potential stands because aspen stands in this area are relatively small, with an average size of 10ha. The necessity for such a large plot size was re-examined using additional field data collected at one site in the Lac La Biche study area. Data on snag density was collected in a long and narrow 4000m^2 plot but recorded in smaller fragments: 50m lengths and both 5 and 10m widths. The density recorded in each smaller plot fragment was cumulatively plotted to determine if variance and mean would stabilize at a smaller plot size. The field data indicated that a 200m by 5m plot was reasonable to capture the variation in snags and was much more practical for field sampling. Based on the variance of the field data, a sample size of 30 was adequate to detect a significant change of 10% or more.

Simulated mean tree density stabilized at a plot size between 300 and 400 m^2. Downed woody material (DWM) cover was determined to have an optimal transect length of between 200 and 300m to record a stable mean and variance. Both trees and DWM, at these plot sizes, had high power at when 25 or more sites were sampled.

Plot size for deciduous saplings was relatively fixed as it corresponded well to previous data collected and to forestry regeneration survey plots (Government of Alberta 2000). However the number of plots per site was manipulated and any number over 15 per site resulted in adequate representation of the mean and variance. Fortunately this also corresponded well with the recommended sample size from the Alberta regeneration survey manual. The recommended sample size for data from visual obstruction cover boards was twenty samples per site collected in a systematic fashion (Haukos et al. 1998) so sapling plots and cover board measurements were coupled, with a sample taken every ten meters, resulting in 21 samples per site. For both saplings and vertical structure data, 25 sites or more were adequate to detect a significant change in means.

Field methods

Snags and live trees

At the edge and in the interior, snags were sampled using a 200m by 5m wide belt transect running parallel to the direction of the seismic line (Fig. 3.1). Within this area all dead standing trees, greater than 5cm dbh, rooted in the ground with less than 45° lean were measured. Each snag had species, dbh, height class, and decay stage recorded. Height classes were as follows: 1) top intact, 2) broken above base of tree canopy crown, 3) broken below crown, and 4) greater than half of tree broken. The height classes were developed based on the positions most likely to break throughout the decay stages of a dead tree. Decay Stages followed Stelfox (1995) and were: 1) recently killed, 2) twigs and leaves lost, bark intact, wood hard, 3) small branches lost, bark beginning to peel, wood still hard. 4) Only major branches remaining, >50% bark remaining, wood softening in places, 5) No branches, <50% bark remaining, wood very soft, and 6) No bark, very decayed wood. Categories 5 and 6 were modified to be more indicative of bark loss and wood decay and not include broken canopy as a criteria. Snag height was recorded separately to determine if any particular decay stage was more or less susceptible to wind damage.

Live trees were sampled, at the edge and interior, within three separate 25m by 5m plots along the continuous belt transect of the snags, a total of 375 m^2 (Fig. 3.2). These plots were separated from each other by 25m. Each adult tree (> 5cm dbh) within the plot had dbh measured and species recorded.

Downed woody material (DWM)

DWM was sampled using the line-intersect method (Devries 1974). A 200m transect line was run parallel to the direction of the seismic line. The transect line was 5m into the edge from the border of the seismic line, at the centre of the snag belt transect (Fig. 3.2). This transect was parallel with another transect 62.5m from the seismic line border.

DWM greater than 5cm diameter and of recent origin had diameter measured at the line intersection. Recent origin pieces were defined as those of decay stage one to four from Lee et al. (1997) (Table 3.1). In addition, the suspected mechanism of tree-fall was recorded. The butt ends of the measured logs were examined for any evidence that they were a) chain sawed, b) broken (as well as position of break), or c) wind thrown (root ball attached).

Table 3.1. Key characteristics of coarse (>5cm diameter) downed woody material (DWM) used to assign decay classes (From Lee et al. 1997).

Decay Class	Key Characteristics
1	Log whole and undecayed; bark, branches, and twigs intact; log elevated on support points wood hard.
2	Log sound, wood hard; twigs mostly lacking; <50% bark missing
3	Some branches remaining; >50% bark missing; wood soft in places
4	Little to no bark remaining; no branches; wood fungi; wood soft with small crevices and small pieces lost.

Estimates of DWM volume were per hectare were calculated using Van Wagner's formula (1968).

$$v = \left(\frac{\pi^2}{8l}\right)\sum_{i=1}\left(n_i d_i^{\,2}\right)$$

Where v = volume per ha, l = length of sample line, n_i = number of intersections, and d_i = mean diameter of coarse woody debris.

Saplings and visual obstruction

Saplings were sampled in twenty-one 1.5m radius plots (7m^2) placed every ten meters along the DWM transect line (Fig. 3.2). The centre of each plot was the DWM intersect line placed 5m from the seismic line edge and 62.5m into the surrounding forest. Each sapling (<5cm dbh) had species and height class recorded. Height categories were: 1= .01m-0.5m, 2 = 0.6m-1.3m, 3 = 1.4m-3m, 4 = 3m-5m, 5 = >5m).

At the centre point of each sapling plot (every 10m) a 3m tall by 0.5m wide cover board was positioned to measure visual obstruction by vertical vegetation as an index of wildlife cover or concealment (Nudds 1977). The board was divided up into six 0.5 by 0.5m squares, alternating between white and yellow. An observer stood back 5m from the board and estimated the percent cover of each square on the board that was covered by vegetation. This method was designed to primarily capture understory herbs, grasses, shrubs, and saplings but any tree branches in the viewer's path were also recorded. Conifer trees, in particular, may change their branch morphology in response to increased light and wind. All squares were averaged to give a mean vegetation cover for use in statistical analysis. Cover at each square was also graphed to examine vertical stratification patterns on the edge and interior forest.

Tree growth

During the 2001 growing season, trees were cored at each of 10 conventional sites and 12 low impact sites up to 20 live trees per replicate stand had a single core removed at breast height (1.3m)(Appendix 3.2). Trees to be cored were chosen from a 100m^2 square sampling area placed directly on the adjacent forested edge and also placed 20m into the interior of the stand. Cores were taken preferentially from dominant trees with up to 20% of the sample being sub-dominant. On the edge of the seismic line the choice of tree was influenced by distance to the line; five of the cored trees were within 5m of the line and five were between 5 and 10m of the line. In the stand interior ten trees were also sampled but these trees were not divided by distance to the line. The majority of cores were taken from aspen, however, balsam poplar, spruce and balsam fir individuals were also sampled when they were the subdominant species in the stand.

In the lab each core had age of tree, radial growth increment per year, and incidence of core rot recorded. Ring width measurements were taken using a binocular microscope (100x magnification) to the nearest 0.01mm. Tree cores were first dried, mounted, and the visibility of rings improved by cutting with a sharp razor blade and then applying white chalk to increase contrast of the wood cells. Crossdating of the ring width profiles (Fritts 1976) was conducted among trees within a stand and then among stands. Signature years (exceptionally narrow or wide rings) were used to assign calendar dates to the rings, and essentially "line up" all of the individual tree cores (Yamaguchi 1990; Peters et al. 2002). Signature years came from two sources: rings from the fastest growing trees I sampled and a master chronology produced by B. Cooke (2001) for his work on forest tent caterpillar outbreaks in northwestern Alberta. Individual ring width series were then ranked with a subjective confidence level (high, medium, or low) based on the match in the visual crossdatings (Lorimer et al. 1999). High confidence trees had five or greater visual matches with the signature years. Trees ranked with moderate confidence if there was a reasonable match with most signature years but may have had some ambiguity. For example, a tree may be shifted one year relative to one or more signature years in the series. This pattern may be the result of a missing or false ring, however, the pattern could be an entirely natural phenomena as forest tent caterpillar outbreaks can have a lagged effect on individual tree's growth (Hogg et al. 2002). A tree ring series was ranked as low confidence when visual cross-dating if there were several mismatched or no matched signature years. A total of ten low confidence trees were left out of analysis for this chapter. High and medium confidence trees were used in all analyses assuming that slight shifts in signature years were due to natural process rather than dating errors. This procedure was also used for conifer species; however, the signature years were only selected from the fastest growing trees sampled. No master spruce or fir chronology was obtained in close proximity to my sites.

Data analysis

Each response variable was examined for evidence of an edge effect using paired t-tests. Each variable was averaged by position (edge or interior) at the stand level. The analysis was structured so that each stand pair was compared, thereby minimizing the influence of site-to-site variation. Data were log or square root transformed, as needed, to meet the assumptions of a normal distribution and equality of variances. Low impact and conventional line types were analyzed separately for edge effect due to the difference in age of the seismic lines. All test were done using SPSS version 10.1 (SPSS Inc. 1999).

Chi-square tests were used to test whether the frequencies of occurrence of categorical variables were being altered due to edge effects. Even if there is no change in the amount of a variable, such as snag density, there may be an effect on the relative frequency of a specific snag characteristic, such as broken tops. The interaction between position and the frequencies of snag height and decay, DWM mortality and decay, and sapling species and height were examined using Chi-square tests.

The study was not designed to test for the effects of line orientation or the interaction of edge and orientation. However, as orientation is very important for light level and wind direction I tested for its effect and its interaction with plot position (edge or interior). Based on a two-way ANOVA model I performed using the regress function in the statistical program Stata (StataCorp 2001). To incorporate the paired design I used the robust cluster method (StataCorp 2001), which relaxes the independence assumption and requires only that the observations be independent among clusters (sites in this case). Robust cluster reduced effective sample size in half (coupling the edge/interior pairs) thereby inflating and correcting the standard errors. Diagonal seismic lines (north-east facing stands) were excluded from this analysis due to low sample size.

Yearly radial growth was averaged for edge and interior samples and plotted over time to determine if there was a pattern of elevated growth on seismic line edges after line clearing. Deciduous and coniferous trees were analysed separately because many of the processes affecting growth may differ between deciduous and coniferous species, which may result in different growth response to the creation of a seismic line. A standardized growth index was calculated for each core to control for variation in growth among individual trees and among stands. Following Chen et al. (1992) and Revel et al. (1984) the relative growth rate is calculated as:

$$RGR = \frac{GR_a - GR_b}{GR_b} \times 100,$$

Where GR_a is the average annual growth for the period after the line is cleared, and GR_b is the average annual growth for the same period length before the line was cleared. This period varies line by line (the exact year of clearing was used) however, generally trees on conventional lines had a 10 year period averaged and low impact lines had a 5 year period averaged. For better comparisons in growth patterns between conventional and low impact line a 5 year growth period after clearing was also calculated for the conventional lines. The relative growth rate was then compared using t-tests between individual edge and interior trees. Diameter of sampled (cored) edge trees was compared to interior forest trees using multiple samples t-test to determine if radial growth significantly affected volume. Incidence of core rot was low in the sampled trees (14% of all cores sampled) and incidence did not vary between the edge and interior so therefore was not examined further.

Results

Tree Mortality

Conventional and low impact seismic lines had slight declines in edge tree density and basal area that were not significantly different from tree density and basal area in the interior forest (Tables 3.2 and 3.3). Average trees diameter (DBH) on both the edges and interior forests bordering conventional seismic lines was 18cm ($p>0.05$)(Table 2). There was no apparent shift in the size distribution of conventional line edge trees relative to the interior forest ($\chi^2 = 9.777$ df = 6 P = 0.134). Trees along edges of low impact seismic lines were 1.36cm larger in diameter than those in the interior ($p<0.05$) (Table 3.3). Tree size distribution on low impact seismic line edges included fewer of the smallest diameter trees (5 to 15cm dbh) on the edge when compared to the interior forest ($\chi^2 = 20.576$ df = 6 P = 0.002). There was no apparent difference in the tree diameter or tree density within the interior of stands along both conventional and low impact seismic lines to indicate differences in the stands sampled. Neither tree density, basal area, nor tree DBH was significantly influenced by line orientation (Tables 3.4 and 3.5).

Volume of coarse downed woody material increased by 18% and 40% along the edges of conventional and low impact seismic lines, respectively ($p<0.05$) (Tables 3.2 and 3.3). Accumulation on the edge was wholly due to trees falling or being pushed into the stand during the line's creation (Fig. 3.4). When trees that were recorded as being cut by chainsaw or pushed by a bulldozer were removed from the test data there was no longer an increase in volume ($p>0.05$ for both conventional and low impact lines). A much larger volume of cut trees is left on the line because the majority of trees cut are piled in an orderly fashion at the side of the clearing and therefore would not be included in either amount. Total DWM volume sampled along low impact lines was lower than the volume recorded along conventional lines (Fig. 3.4). DWM volume was about $22m^3$ per higher along both the edge and interiors of stands facing south (east-west oriented lines) than stands facing west (north-south lines) along low impact seismic lines. Volume along low impact seismic lines varied significantly with orientation, without a significant effect of position or a significant interaction ($p<0.05$) (Table 3.5). There was no difference in amount among orientations of conventional lines (Table 3.4).

Snag density on both conventional and low impact seismic neither increased, as would be expected if live trees were damaged, nor did density decrease, due to blow down of existing snags (Tables 3.2 and 3.3). Line orientation did not affect snag density (Tables 3.4 and 3.5). Snags on both the conventional line edge and interior were equivalent in diameter (15cm dbh) but the distribution in diameter between the edge and interior varied significantly ($\chi^2 = 37.379$, df = 10, p = <0.001). Primarily, this analysis indicates a significant decrease in the proportion of small snags on the edge versus the interior forest (Fig. 3.5a). Proportion of broken snags did not increase on the edge ($\chi^2 = 0.460$ df = 3 P = 0.794) (Fig. 3.6a). This is unsurprising as most snags break at the base (Harper 1999).

There were 30% fewer snags per hectare recorded in stands along low impact lines when compared to conventional line stands. Low impact seismic line snags were also two centimetres smaller than the average snag on conventional lines. However, snags along edges of low impact seismic lines had a larger diameter (dbh) than interior trees with an average increase of 1.18cm ($p<0.05$) (Table 3.3). In addition, stands facing south had a larger average diameter snag than stands facing west for both the edge and interior positions. Orientation of the low impact lines was a significant factor in snag diameter in addition to the effect of position, however there was not a significant interaction between position and orientation (Table 3.5).

Increased snag diameter, without a concurrent drop in density, might be explained by a decrease in the number of small snags with a co-occurring increase in the number of larger snags. More small snags on the edge may have fallen over while more mature trees died thereby increasing the average diameter while leaving the overall density unchanged. This was not evident from the average DWM diameter ($t = -1.269$, $df = 30$, $p = 0.214$). However, there was a greater percentage of small diameter snags in the interior forest ($\chi^2 = 23.627$, $df=6$, $p = 0.001$) as compared to the edge (Fig. 3.5b). Further, there were less snags on the edge that were damaged (without a major or minor break) than in the interior forest ($\chi^2 = 7.7092$ $df = 3$ $P = 0.052$) (Fig. 3.6b).

Tree Growth

Growth of deciduous trees on conventional and low impact seismic line edges was initially higher than growth of trees in the interior forest (Fig. 3.7 and Table 3.6). Within the first five years after clearing, deciduous trees on conventional line edges increased growth by 82% and growth of trees on edges of low impact lines doubled (Fig. 3.7). Much of this response may have come from trees on the very edge of the line clearing. On conventional lines trees within 5m of the line had relative growth rates that were 70% higher than those trees between 5 and 10m away ($t = 2.00$, $df = 36$, $p = 0.053$). Similarly, deciduous trees closest to the edge of low impact seismic lines had growth rates 80% higher than trees slightly further from the forest edge, but the difference was not significant ($t = 1.538$, $df = 65$, $p = 0.129$). In general, forests adjacent to conventional lines had greater average growth rates than forests adjacent to low impact lines (Fig. 3.7).

Increased deciduous tree growth along conventional seismic lines was not sustained. After ten years of growth, edge trees on conventional lines no longer had a significantly increased relative growth rate (Table 3.8). Peak growth generally occurred 5 years after clearing (~1995) and then levelled off at a yearly growth equivalent to the interior trees (Fig. 3.5a). After ten years there was also no longer any difference between those trees growing directly on the edge and those slightly further into the forest ($t = 0.076$, $df = 36$, $p = 0.940$).

Conifer species did not respond in the same manner as deciduous trees. Generally, growth trends for coniferous species were declining in a typical negative exponential growth curve (Fig. 3.8) resulting in negative relative growth rates (Fig. 3.9). After clearing of a conventional line there was a 25% increase in the average yearly growth, beginning after 3-4 years after clearing, which seemed to be sustained (Fig. 3.8a). This growth was not statistically significant in either the five or ten year periods after seismic line creation (Table 3.6). Conifer trees on low impact seismic line edges did not show any increased growth in the five years after the clearing of the line (Figs. 3.8b and 3.9a, and Table 3.6). Neither conventional nor low impact seismic lines had a difference in growth response between those conifer trees near the seismic line edge (within 5m) versus those further away (between 5 and 10m)(Conventional: $t = 0.835$, $df = 13$, $p = 0.419$; LIS $t = -.039$, $df = 9$, $p = 0.743$).

Increases in radial growth did not result in significantly larger diameter (DBH) trees. Deciduous trees along the edges of conventional seismic lines were only 1.16 cm larger than interior forest ($t = .686$, $df = 80$, $p = 0.495$). Deciduous trees along edges of low impact seismic lines were only 0.72 cm larger than trees in the interior forest ($t = .654$, $df = 129$, $p = .514$). In the 2002 data, diameter of trees along edges of conventional lines sampled in 2001 was 0.42 cm greater than the interior forest ($p > 0.05$) (Table 3.2). However, diameter of trees sampled on low impact seismic lines, in 2002, was greater than interior forest by 1.36 cm ($p<0.05$) (Table 3.3).

Recruitment

Aspen (*Populus tremuloides*) was the dominant species recruiting on both line types (60% of stems), with balsam poplar (*Populus balsamifera*) and paper birch (*Betula papifera*) next most common (10% of stems each). The species composition did not vary significantly between the edge and the interior (Conventional: $\chi^2=5.131$, df = 4, p = 0.274; LIS: $\chi^2 = 4.303$, df = 4, p = 0.367).

Density of young trees on the edge of both conventional and low impact seismic lines increased significantly (Tables 3.2 and 3.3). Conventional lines had a 48% increase in suckering on the edge of the line whereas low impact lines had a lesser response with only a 19% increase in sucker density on the edge. The interior forest of both line types had the same sapling density. Relative proportion of saplings in each height category was not significantly different between the edge and the interior of the forest. Edges only increased in sapling number and not in proportion of taller trees (Conventional: $\chi^2=1.339$, df = 4, p = 0.855; LIS: $\chi^2 = 1.573$, df = 4, p = 0.814). Orientation did not significantly influence sucker density in either conventional or low impact seismic line edges (Tables 3.4 and 3.5) although south-facing conventional line sites had five times the increase in sapling density as compared to the west facing sites.

Both line types had increased cover (visual obstruction) on the edge (Tables 3.4 and 3.5) (Fig. 3.10). Conventional lines had a 40% increase in average cover while low impact lines had a 22% increase in cover on the line edge when compared to the interior forest. Differences between the two lines types are evident when cover at each height is compared for the edge and interior (Fig. 3.10). At all heights, and particularly at the tallest height (3m), cover at the edge of conventional lines was greater than cover at the edge of low impact seismic lines. For this variable the two seismic line types occurred in stands that also had different amounts of interior forest cover. The interior forest in conventional line stands had 33% more cover on average than the interior forest in stands along LIS lines. Increased visual obstruction along edges was not solely attributable to regenerating tree density. Shrub species that were generally common throughout the stand had increased height and cover at the seismic line edge. This was particularly true for *Salix* and *Corylus cornutus* patches.

Discussion

Mortality

No increases in natural tree mortality were detected on the edge of either conventional or low impact seismic lines. This result is surprising as increased tree mortality was reported on cut-block edges in aspen mixedwood forests within the same study area (Harper and MacDonald 2002). Additionally, wind damage on edges is frequently reported for other ecosystems (Murcia 1995).

Edges of conventional seismic lines have had ten years to develop edge effects and but have also had time to stabilize after any initial impacts of sudden change in microclimate. Harper and MacDonald (2002), using a before/after design, found high mortality of standing live and dead trees in the first year following edge creation. Ten percent of edge trees were broken due to increased wind at the edge. After this immediate damage mortality rates for the remaining trees fell to levels below the natural rate in interior forest indicating there were no longer any trees left that were susceptible to windbreak or blow-down (Harper and MacDonald 2002). Wind mortality on seismic line edges may have occurred for the most susceptible individuals immediately after clearing but with our retrospective study we were unable to detect any significant trends. We did not see any accumulation of DWM, for instance, that would indicate increased mortality but on low impact seismic lines average tree DBH was much larger on the edge compared to the interior forest. However, an alternate explanation is that selective avoidance of merchantable trees along the meandering seismic path increased average DBH. Avoidance of large trees on low impact seismic lines may also explain the lower frequency of small trees on the edge.

Relative to conifer dominated (Chen et al. 1992; Burton 2002) or tropical forests (Williams-Linera 1990; Laurance et al. 1998) with strong edge effects, aspen mixedwood stands may be less prone to wind damage. Aspen dominated mixedwood stands have reduced susceptibility to wind damage because aspen trees have flexible, permeable canopies that are less susceptible to increased sway from high wind. Aspen also have deep root systems to support the trees during wind gusts (Navritil 1995). The magnitude of windthrow mortality is related not only to the individual stability of a tree or stand but also to the degree and extent of interruptions in the forest canopy (Navritil 1995). Even though wind speed may increase in the seismic line opening, the relatively short distance of the clearing prevents the wind from reaching high velocities (Flesch and Wilson 1999a, 1999b).

Wind firmness of individual trees, if not accompanied by development of a side canopy or similar vegetation structure (Matlack 1993; Cadenasso and Pickett 2001), may not be enough to prevent wind damage of snags. For instance, increase in turbulence due to the seismic line edge may not damage sturdy live trees however may damage the unstable dead standing trees (Navritil 1995). Snag density overall was not significantly altered by edge effects. However, both conventional and low impact lines showed a decrease in the proportion of small diameter snags on the edge versus interior forest. Harper and MacDonald (2002) found much higher snag breakage rates than tree mortality rates on the edges of clearcuts. Most of snags that were blown over or broken were tall and thin. Many of the small diameter snags, likely trees that had died due to aspen self-thinning, may have been blown over because they were most susceptible to wind damage.

On low impact lines snag damage was more severe than on conventional line edges. An increase in the average size of snag coupled with a change in the proportions of small diameter and intact snags on the edge indicates that in addition to blow down of pre-clearing snags standing live trees were dying. Wind speed may have been higher on low impact lines than conventional lines. Indentations in the edge of a stands, especially V- or egg-shaped openings, produce a funneling effect that increases wind speed (Navritil 1995). For example, wind damage is frequent on road turns, burrow pits, and wellsites.

Growth

It was expected that increased growth in canopy trees would be detected where shading and competition had been removed. Seismic line creation resulted in increased growth for deciduous trees along both conventional and low impact seismic line edges. Increased growth was strongly related to proximity to the seismic line for deciduous trees. Light levels likely peaked within 5m from the seismic line boundary. Penetration of light into the adjacent forested edge of 9m wide strip-cuts in 40 year-old aspen forests indicates that light rapidly declines 5m from the edge (Groot et al. 1997). However, the larger the opening the greater distance light will penetrate (Groot et al. 1997). The wider conventional line did not have a larger magnitude of growth response on the edge in comparison to the low impact seismic lines. However, the greater annual growth of interior trees on conventional lines (Fig. 7b) suggests that light may be penetrating 20 to 30m into the adjacent forest and reaching the interior plot. Consequently any edge effects on conventional lines due to increases in light, possibly unmeasured, may penetrate a distance of up to 30m.

A surprising result was the short duration of the growth response. Conventional seismic line edge trees only had elevated growth for a period of five years. After ten years the edge trees no longer had an elevated yearly growth. It is unlikely that light levels dropped drastically in that period because seismic lines have a very slow reforestation rate (Revel et al. 1984; Osko and MacFarlane 2000). This suggests that aspen growth rate is, in part, related to light but is also determined by other biotic and abiotic factors. Aspen growth can be sensitive to high atmospheric water vapor pressure deficits (Hogg et. al 2000). Increases in wind and light on the seismic line may increase the daily vapor pressure deficit (Matlack 1993). This, coupled with regional droughts in 1998 and 1999, may have caused enough stress on the edge trees to slow their growth. Suckering at the edge may have diverted resources need for radial growth (Peterson and Peterson 1992). The lack of consistent aspen growth response to conventional seismic lines in Alberta's foothills (Bella 1986) may be attributable to some of these other factors. It is likely that growth of edge trees on low impact seismic lines will also stabilize to a yearly growth equivalent to interior trees.

It was expected that conifer trees on the edges of seismic lines would have a strong growth response to increases in light. Both Revel et al. (1984) and Bella (1986) reported increases in growth rates of conifer species along seismic lines. In particular Bella (1986) found that white spruce increased in yearly growth by 15-20% with 5 years of line clearing. Understory conifer are expected to put on considerable growth if "released" from the overstory shade. Yang (1991) found that the highest growth responses come from trees aged 26-45 years of age which is the age of conifer trees growing in the understory of stands in this study. The white spruce and balsam fir trees appeared to respond to the clearing of conventional lines even though the 5 or 10 year growth averages were not significantly higher than interior trees. However the increased growth pattern on conventional lines appeared to be sustained, unlike aspen, so in the future the small incremental gains may add up to significant diameter increases for the coniferous edge trees in the understory of aspen stands.

Recruitment

Increased density and cover of young deciduous trees at the edges of seismic lines was likely a direct response to increased light at the edge coupled with stimulation from tree removal (Peterson and Peterson 1992). This is expected because, as early successional species, aspen and balsam poplar are adapted to disturbance by fire with rapid regeneration primarily through suckering from the roots of the fire-killed trees.

However seismic lines edges did not have the exact response as edges adjacent to larger, fire-like, disturbances. Harper (1999) found much greater densities of suckers regenerating at cut-block edges. Even after 5 years of self-thinning, aspen sucker density was approximately seven times higher on cut-block edges than on seismic line edges. Cut-blocks are much more similar to fires than are seismic lines; the combination of the complete removal of apical dominance (Steneker 1976) as well as high light levels warming the soil and stimulating roots leads to large amounts of suckering (Maini and Horton 1966). Simply put, they recorded a greater response due to a greater disturbance. Harper (1999) found a high number of immature trees on the 16 yr old edge indicating the suckers developed into trees and subsequent shading prevented further recruitment.

Conventional seismic lines were 10 years-old and still had significantly higher amounts of young trees on the edge versus the interior forest but, in contrast, did not have significantly taller saplings or significantly higher numbers of immature trees on the edge. A seismic line is a unique disturbance in that the line itself regenerates very slowly allowing a steady level of elevated light intensity. However the opening created by the line is quite small, similar to a gap, and the increase in light is a relatively small proportion of open conditions. Light on the edge must have been intense enough to stimulate and sustain aspen suckering but not intense enough to support growth of suckers to maturity within the ten years since clearing. Light is not critical for initial sucker growth but is required for good survival and production. Light at half the intensity of full sunlight is enough to reduce the sucker production to less than 10% of that at full light (Peterson and Peterson 1992). In aspen forest gaps Cumming et al. (2000) found elevated recruitment after gap formation but that gaps were not associated with increased height growth of young aspen. Kembel (2001) found that within aspen dominated canopies deciduous suckers did not respond to canopy gaps. Suckers were found throughout the stand in low densities yet were not developing into canopy trees. Further reduction in light due to a smaller opening in the canopy on low impact lines might explain why low impact lines have lower densities of regenerating suckers; a lack of stimulation as well as poor survival.

Increases in vegetation cover was not solely attributable to sucker density. Shrub species increased in height and in leaf cover as indicated by our total cover measurements. Up to a 3m height, shrubby cover was higher than the interior forest. Increased shrub growth is a common response to edge creation (Ranney et al. 1981; Williams-Linera 1990; Matlack 1993). Shrub cover, measured as leaf area index, was higher up to 3m into the edge of experimental strip-cuts in 40 year-old aspen forests (Groot et al. 1997). Increases in visual obstruction due to shrub cover is likely an edge effect that could influence wildlife habitat and behaviour due to changes in depth-of-vision, movement between the line and forest, and bird nesting habitat, for example.

Effects of orientation

Orientation is very important to the depth of microclimate and vegetation edge effects (Wales 1972; Palik and Murphy 1990; Matlack 1993; Chen et al. 1995). Chen et al. (1995) found that the influence of orientation was critical in determining the magnitude of microclimate edge effects in Oregon forests. Changes in microclimate were strongest and penetrated furthest at south- to west-facing edges, as would be expected of all northern latitudes (Chen et al. 1995). It would have been unsurprising to detect differences due to line orientation in this study, however, the majority of variables were not significantly influenced by orientation. The only two variables that were different between south- and west-facing sites, snags and DWM, had no significant interaction with edge. Orientation effects, in this case, might be a result of stand differences.

Conclusions

Edge influence was mostly restricted to increases in productivity. Edge effects vary considerably among edge type, ecosystems, and time since edge creation (Chen et al. 1992, Matlack 1993, 1994; Harper and MacDonald 2002; Burton 2002). It is likely that the narrow construction of seismic lines prevents significant alterations in microclimate thereby reducing changes in vegetation structure. Edge effect still may occur, however, at larger openings such as occur when seismic lines intersect. There may also be synergistic microclimate effects as the future density of lines increases resulting in very tight spacing through the boreal region.

This study focused on the response of aspen dominated forests. Aspen mixedwood stands may be resilient to edge effects due to relatively high within stand environmental heterogeneity (Kembel 2001) and the strong influence of frequent natural disturbance (fire, insects, diseases) on regeneration processes.

However, conifer dominated and more mixedwood forests may be much more susceptible to wind damage on edges (Chen et al. 1992; Burton 2002) and have more abrupt changes in microclimate (Chen et al. 1995). Future research on seismic lines should include different stand types.

The cumulative impact of industrial development is expected to rapidly alter the once contiguous forested landscape into a forest reduced in extent and one that is increasingly fragmented. Seismic line edge effects measured in this study will not contribute significantly to negative ecological (effective habitat) or economic (tree volume loss) cumulative effects. Therefore, the primary concern is the initial loss of forested area. With implementation of better seismic line practices, reducing line widths even further, any impacts of seismic lines can be prevented in the future. For the present time, efforts can be directed at restoring forest in the area currently covered by seismic lines.

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Table 3.2. Comparison of means of vegetation structure variables between the edges of conventional seismic lines and the interiors of the surrounding aspen stands (n = 30). Significant results are bolded (Alpha = $p<0.05$). Data are means ± 1 SE.

	Edge	Interior	*t*	*p*
Tree Density (no./ha)	1097 ± 81	1145 ± 98	-0.614	0.544
Tree BA (m^2/ha)	27.19 ± 1.59	28.03 ± 1.46	-0.631	0.533
Tree DBH (cm)	18.00 ± 0.55	17.58 ± 0.47	1.023	0.315
Snag Density (no./ha)	336 ± 28	344 ± 30	-0.353	0.726
Snag dbh (cm)	15.48 ± 1.08	15.28 ± 1.26	0.312	0.757
DWM volume (m^3/ha) (slash included)	**77.36 ± 8.43**	**65.67 ± 7.29**	**2.424**	**0.022**
DWM volume (m^3/ha) (no slash)	67.56 ± 7.79	65.67 ± 7.29	0.446	0.659
Sapling Density (no./ha)	**5671 ± 707**	**3828 ± 488**	**2.936**	**< 0.001**
Vertical Shrub Cover (%)	**31.20 ± 2.38**	**22.31 ± 2.09**	**4.057**	**< 0.001**

Table 3.3. Comparison of means of vegetation structure variables between the edges of low impact seismic lines and the interiors of the surrounding aspen stands (n = 31). Significant results are bolded (Alpha = p<0.05). Data are means ± 1 SE.

	Edge	Interior	*t*	*P*
Tree Density (no./ha)	1082 ± 111	1152 ± 105	-0.844	0.405
Tree BA (m^2/ha)	28.13 ± 1.51	28.17 ± 1.71	-0.027	0.979
Tree DBH (cm)	**18.94 ± 0.80**	**17.58 ± 0.68**	**2.229**	**0.033**
Snag Density (no./ha)	239 ± 21	246 ± 23	-0.331	0.743
Snag dbh (cm)	**14.15 ± 0.87**	**12.97 ± 0.77**	**2.047**	**0.049**
DWM volume (m^3/ha) (slash included)	**59.56 ± 4.92**	**42.34 ± 3.50**	**4.580**	**<0.001**
DWM volume (m^3/ha) (no slash)	41.13 ± 3.49	42.34 ± 3.50	-0.250	0.804
Sapling Density (no./ha)	**4694 ± 497**	**3959 ± 460**	**2.364**	**0.025**
Vertical Shrub Cover (%)	**20.37 ± 2.01**	**16.72 ± 1.74**	**2.093**	**0.045**

Table 3.4. Significance of position, orientation, and the interaction within the two-way ANOVA, using robust cluster, for conventional seismic lines. Significant values are bolded (Alpha = $p<0.05$).

Variable	Factor		
	Position	Orientation	Interaction
Tree Basal Area (m^2/ha)	0.855	0.659	0.879
Tree Density (Stems/Ha)	0.758	0.553	0.938
Tree Average DBH (cm)	0.859	0.771	0.402
Snag Basal Area (m^2/ha)	0.668	0.090	0.923
Snag Density (Snags/Ha)	0.937	0.368	0.725
Snag Average DBH (cm)	0.722	0.577	0.534
Volume (m^3/ha)	0.463	0.616	0.437
Density (Pieces/200m)	0.244	0.903	0.300
Sapling Density (Stems/ha)	0.133	0.154	0.460
Average % Cover	0.273	0.343	0.420

Table 3.5. Significance of position, orientation, and the interaction within the two-way ANOVA, using robust cluster, for low impact seismic lines. Significant values are bolded (Alpha = $p<0.05$).

Variable	Factor		
	Position	Orientation	Interaction
Tree Basal Area (m^2/ha)	0.600	0.858	0.566
Tree Density (Stems/Ha)	0.315	0.576	0.071
Tree Average DBH (cm)	0.091	0.181	0.684
Snag Basal Area (m^2/ha)	**0.022**	**0.006**	0.193
Snag Density (Snags/Ha)	0.706	0.526	0.222
Snag Average DBH (cm)	**0.043**	**0.018**	0.850
Volume (m^3/ha)	0.361	**0.038**	0.165
Density (Pieces/200m)	0.903	0.088	0.447
Sapling Density (Stems/ha)	**0.002**	0.112	0.835
Average % Cover	0.969	0.749	0.102

Table 3.6. Results of independent samples t-tests on the relative growth rates (RGR %) of individual trees on the edge of conventional and low impact seismic lines and in the interior forest.

Line Type	Years Since Clearing	Tree Species	Position	n	Mean RGR ± SE	*t*	*df*	*p*
Conventional	10	Deciduous	Edge	38	68.90 ± 13.58	0.534	80	0.595
			Interior	44	59.47 ± 11.50			
		Coniferous	Edge	15	1.79 ± 11.34	1.142	40	0.260
			Interior	27	-9.93 ± 4.40			
	5	Deciduous	Edge	38	**85.29 ± 11.41**	**2.756**	**80**	**0.007**
			Interior	44	46.92 ± 8.39			
		Coniferous	Edge	15	1.35 ± 5.71	1.688	40	0.099
			Interior	27	-11.79 ± 4.85			
Low Impact	5	Deciduous	Edge	67	**42.36 ± 7.87**	**2.234**	**129**	**0.027**
			Interior	64	19.82 ± 6.23			
		Coniferous	Edge	11	-20.71 ± 11.86	0.153	19	0.880
			Interior	10	-22.94 ± 7.77			

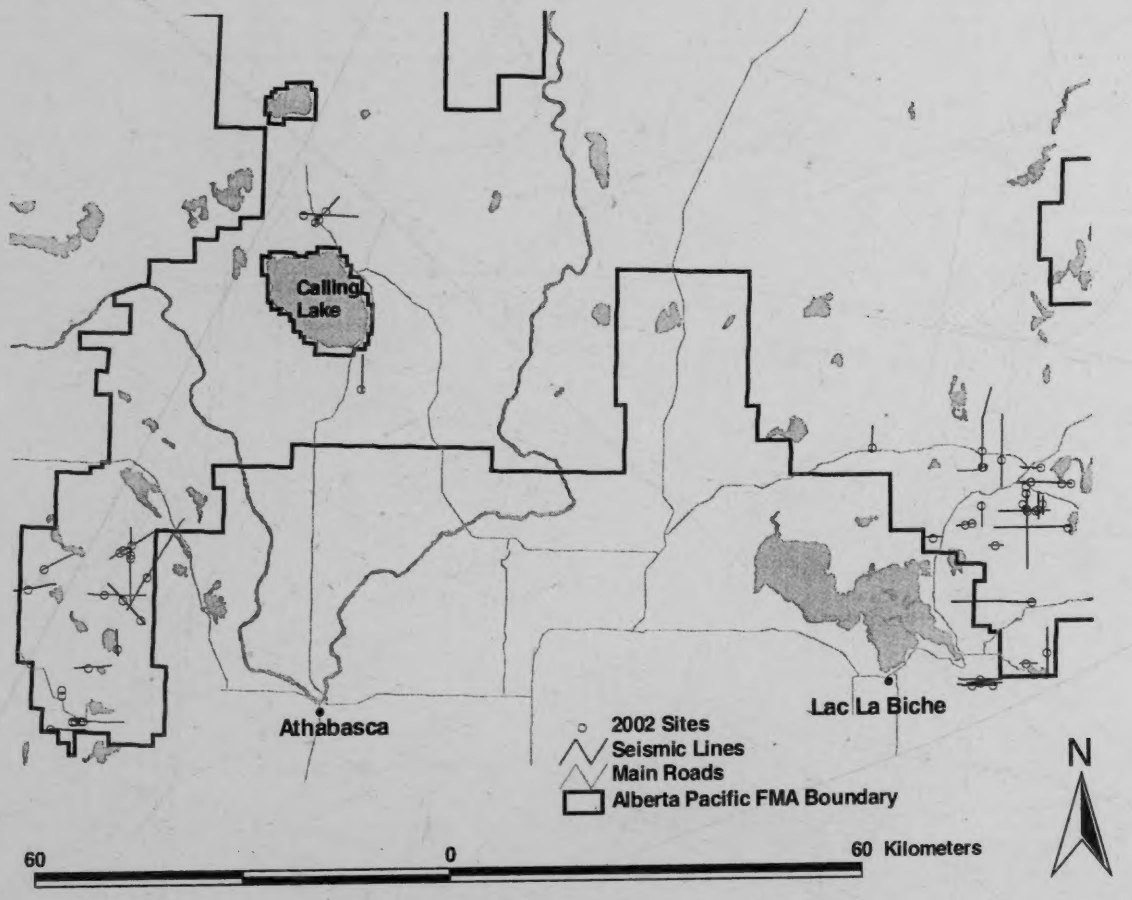
Calling Lake
Athabasca
Lac La Biche
2002 Sites
Seismic Lines
Main Roads
Alberta Pacific FMA Boundary
60
0
60 Kilometers
N

Figure 3.1. Location of sites sampled in 2002 on both conventional and low impact seismic lines.

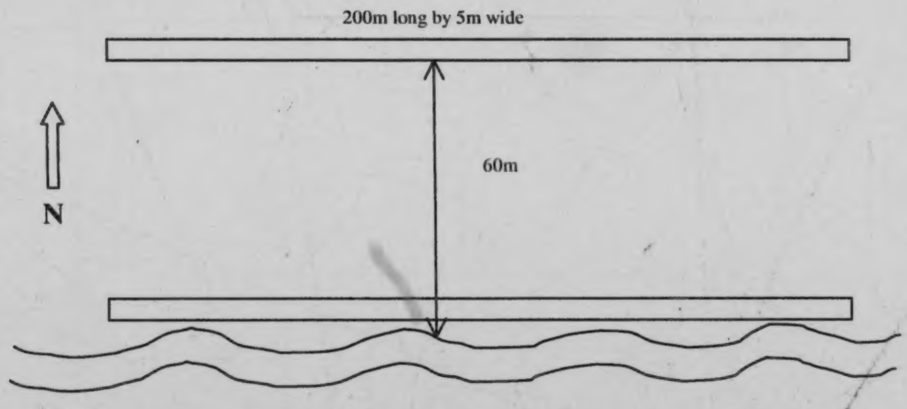
200m long by 5m wide
60m
N

Figure 3.2. Representation of a low impact seismic line with edge and interior sampled areas (conventional lines have straighter edges). On the north edge, one plot is placed 2.5m into the forest from the seismic line and the other is 60m from the seismic line into the forest. Sampled areas paralleled the orientation of the seismic line over a distance of 200m. Both sampled areas were buffered from all stand boundaries by 50m. Diagram not to scale.

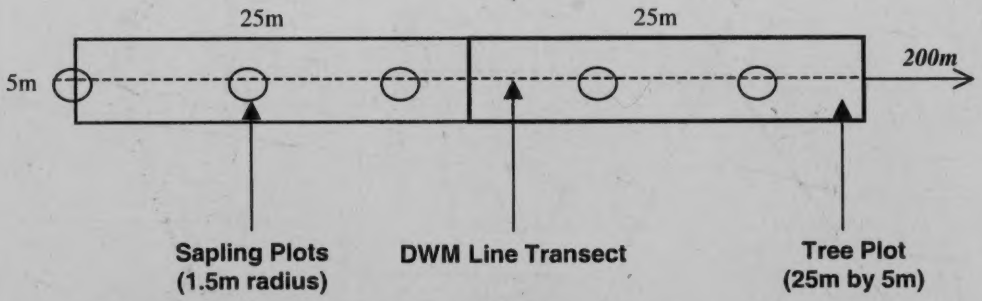
25m
25m
200m
5m
Sapling Plots
(1.5m radius)
DWM Line Transect
Tree Plot
(25m by 5m)

Figure 3.3. This figure shows the first two segments of the 200m sampling area. Snags were sampled throughout the entire 200m x 5m (belt transect). Live trees are sampled in three 25m x 5m plots staggered over the 200m. The downed woody material (DWM) transect is positioned 5m into the edge, at the centre of the 5m wide plot. Sapling plots (1.5m radius) are placed every 10m centred on the DWM transect. Diagram not to scale.

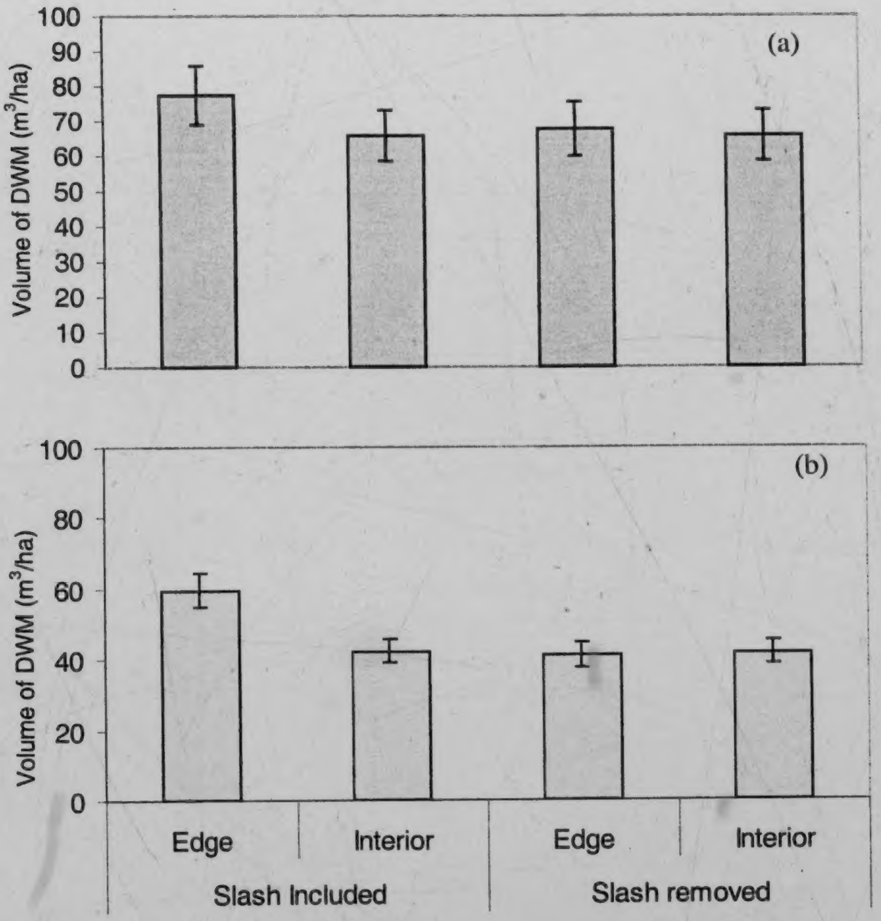

Figure 3.4. Volume of recently fallen DWM for (a) conventional and (b) low impact seismic lines on the line edge and in the interior of the adjacent stand. Bars to the left include all pieces encountered. Bars to the right include only pieces that were not cut or bulldozed during the clearing of the line. Data are means ± 1 SE

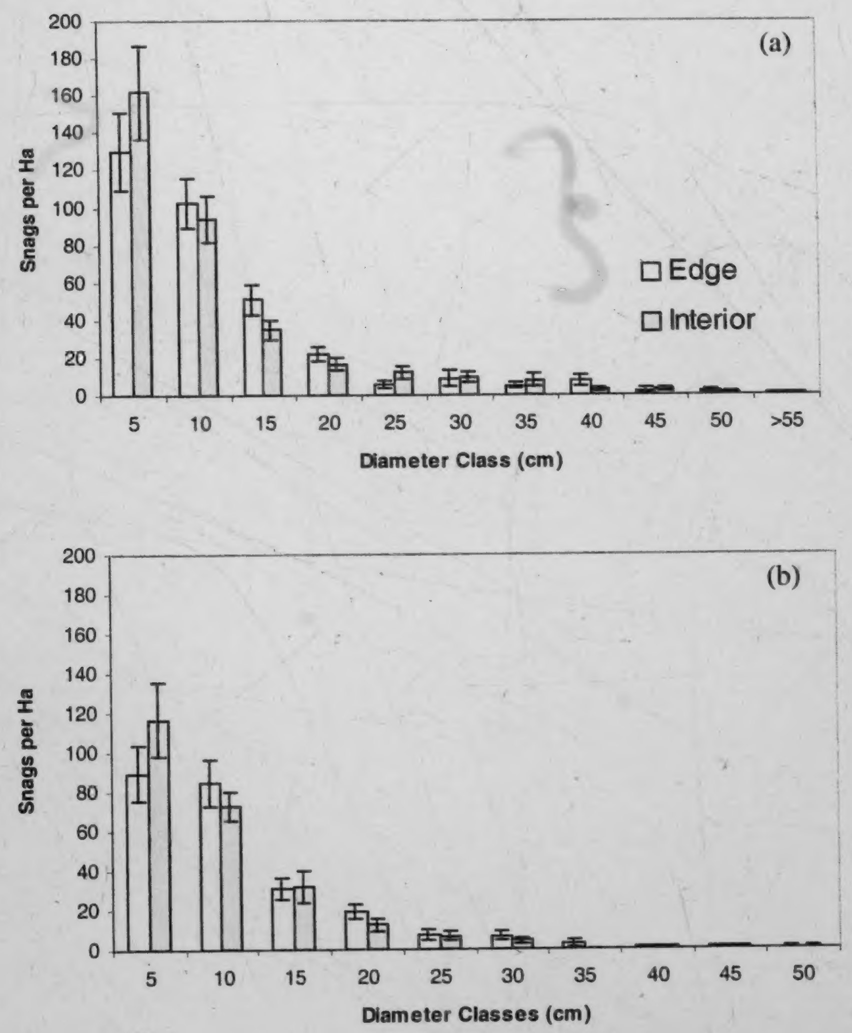

Figure 3.5. Mean density (± 1 SE) of snags by diameter (dbh) classes along the edges of (a) conventional and (b) low impact seismic lines as well as in the interior forest.

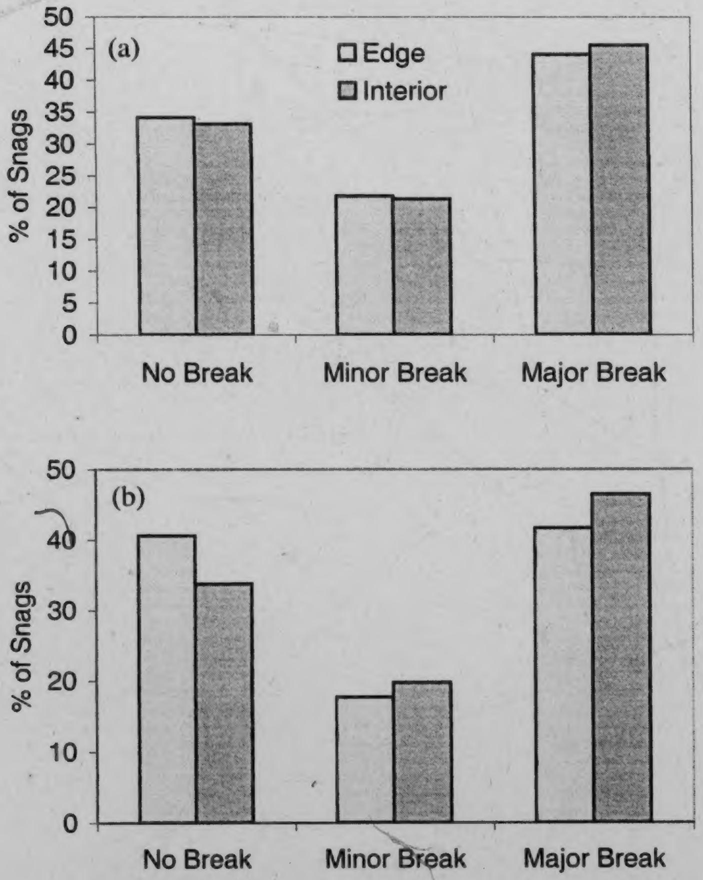

Figure 3.6. Percentage of snags on the edge and in the interior forest of (a) conventional and (b) low impact seismic lines within three height categories: no break in the canopy, a minor break greater than half way up the tree and a major break with more than half of the tree trunk broken away.

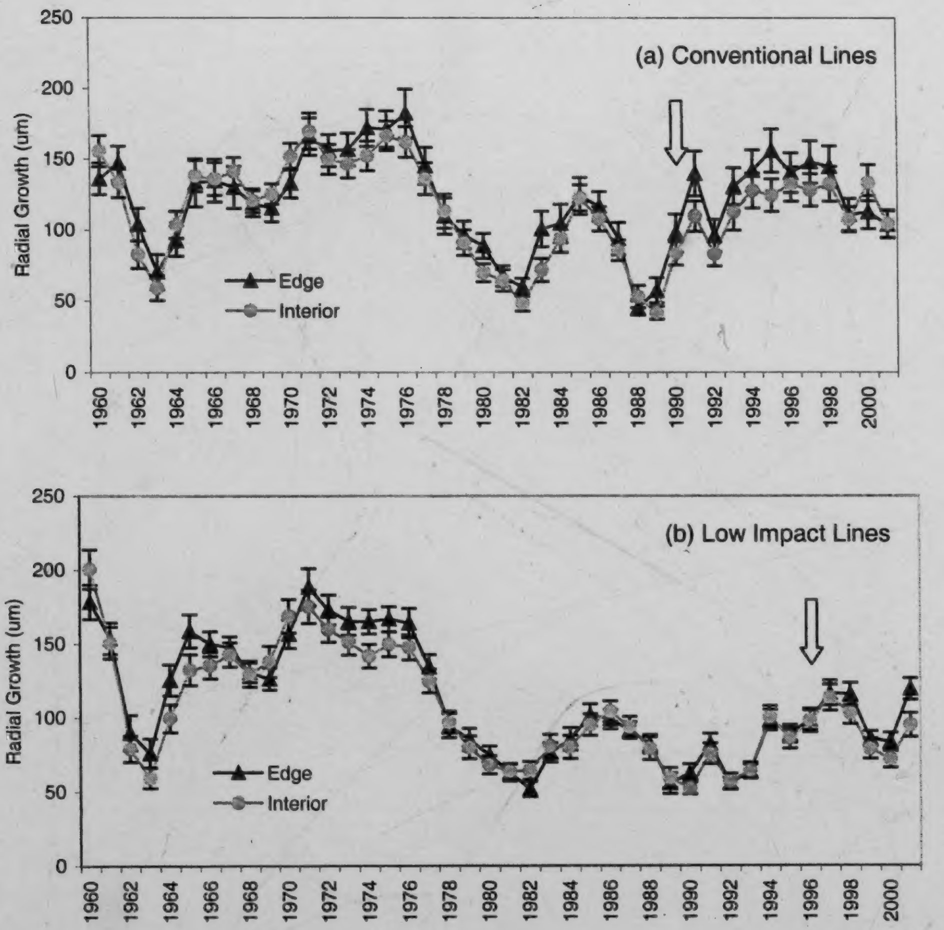

Figure 3.7. Yearly radial growth (μm) of deciduous trees (aspen and balsam poplar) along the edge and interior of (a) conventional and (b) low impact seismic lines over the past forty years. Year of seismic line clearing occurred is shown by arrow. Data are means (±1 SE) for individual trees on the edge and interior, respectively, of 38 and 44 conventional lines and 67 and 64 low impact seismic lines.

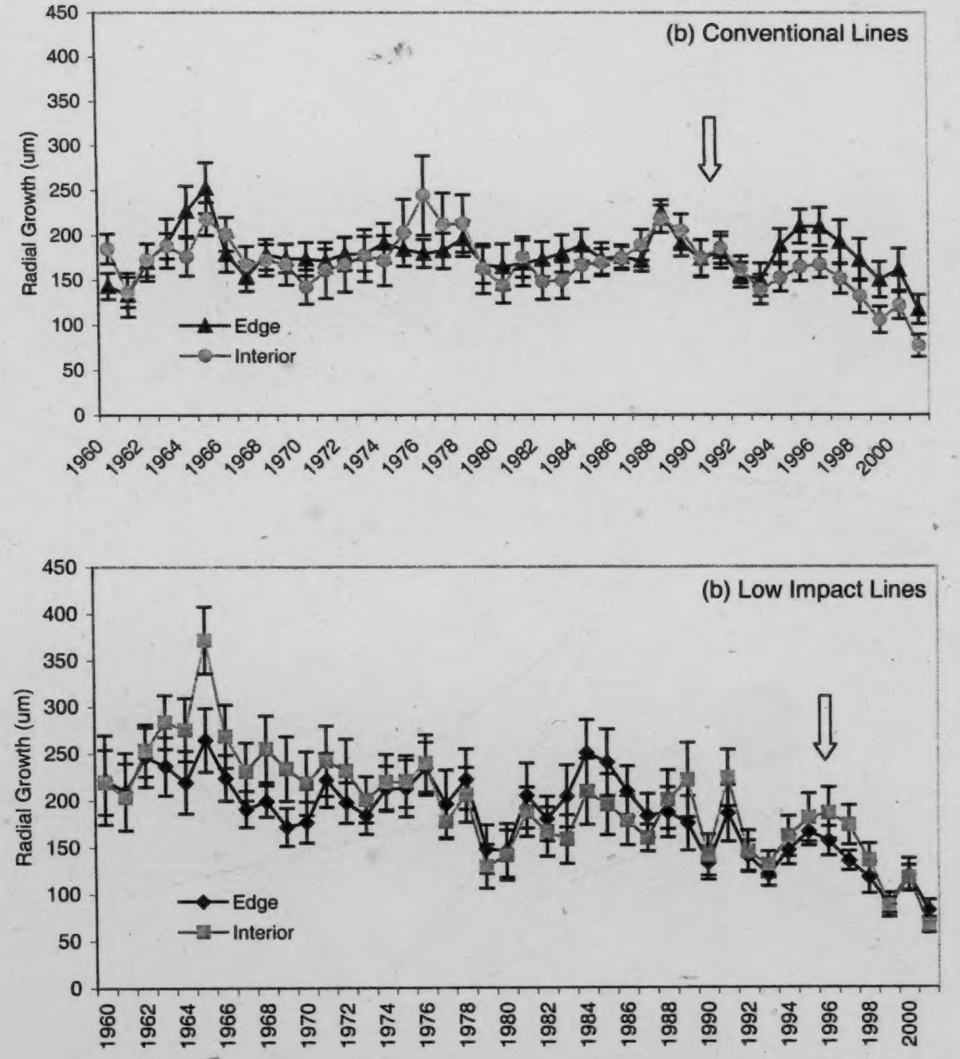

Figure 3.8. Yearly radial growth of coniferous trees (white spruce and balsam fir) along the edge and interior of a) conventional and b) low impact seismic lines over the past forty years. Year of seismic line clearing occurred is shown by arrow. Data are means (± SE) for individual trees on the edge and interior, respectively, of 15 and 27 conventional lines and 11 and 10 low impact seismic lines.

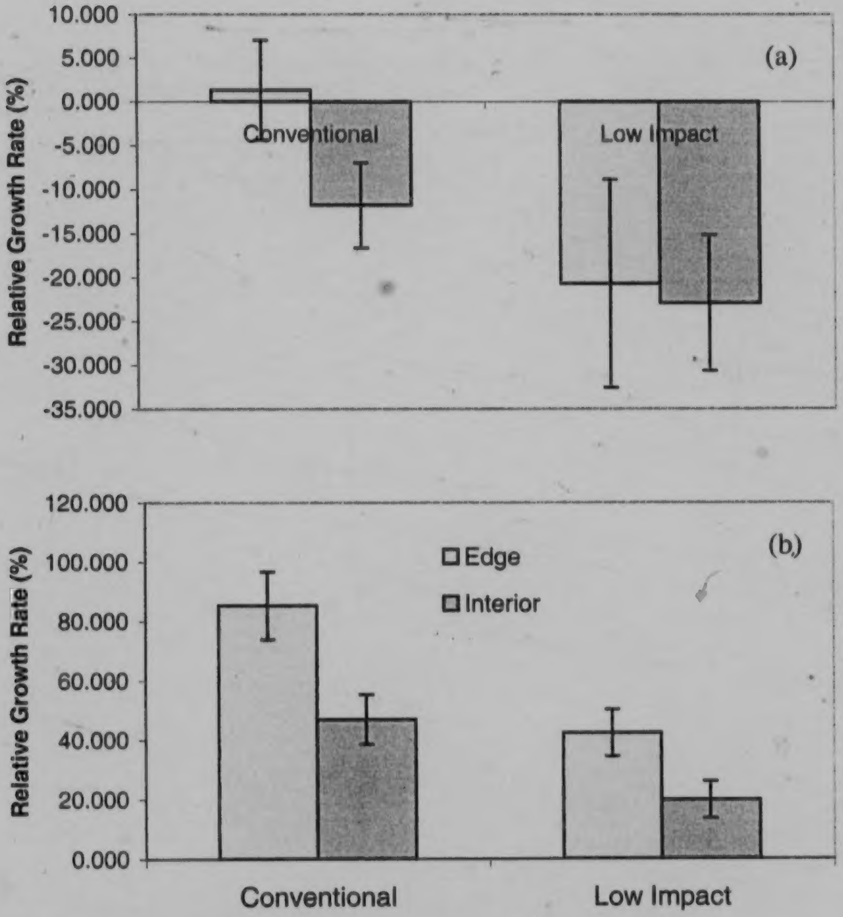

Figure 3.9. Increases in relative growth rate of (a) coniferous and (b) deciduous trees on conventional and low impact seismic lines on the adjacent forest edge and interior over a five year period following seismic line clearing. Data are means ± 1 SE.

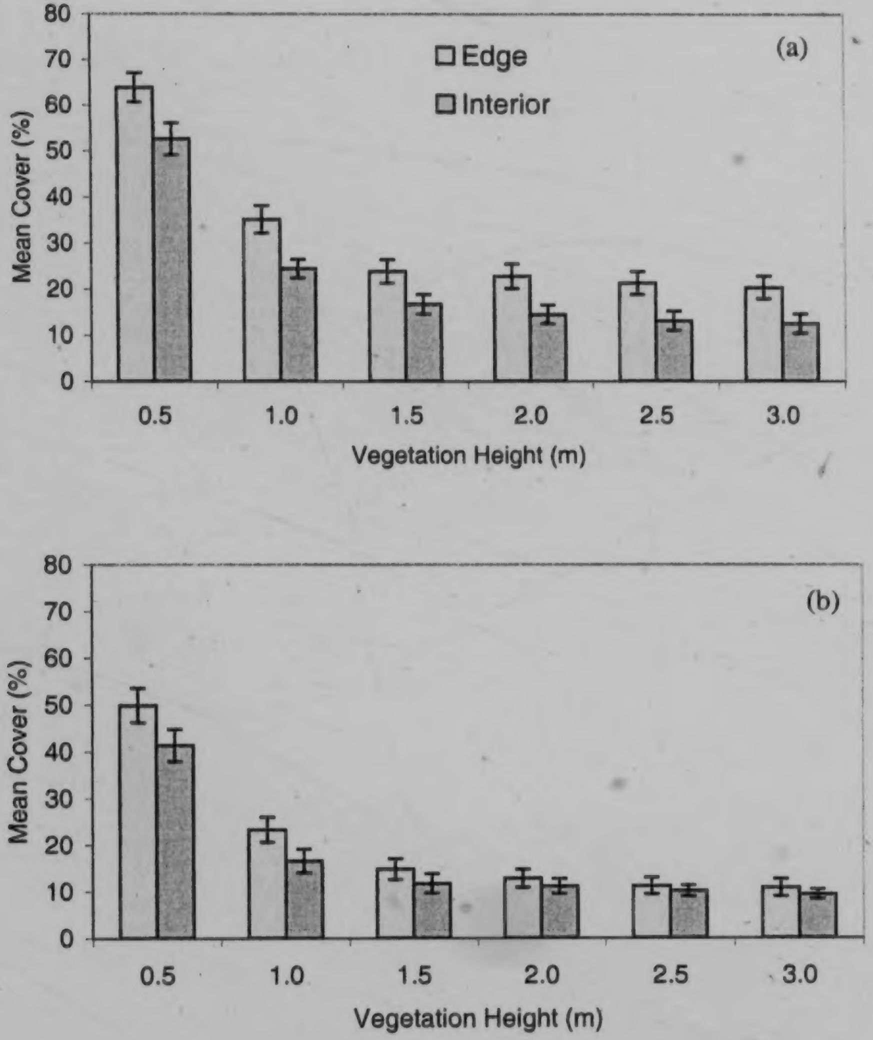

Figure 3.10. Mean (± SE) vertical shrub cover at the edge and interior of (a) conventional and (b) low impact seismic lines. Cover was recorded in $0.25m^2$ plots at six heights starting at the ground level to a maximum height of 3m.

CHAPTER 4.
UNDERSTORY PLANT COMMUNITY COMPOSITION ON SEISMIC LINES AND ALONG SEISMIC LINE EDGES

Introduction

Alberta's northern forests have only recently been subjected to industrial development, relative to other ecosystems (i.e. the prairies). However, since the 1950s, the boreal forest has been altered by the forestry, oil and gas, and agriculture industries, as well as by urban expansion (Alberta Environmental Protection 1998). The rate of development has accelerated in the last decade (Schneider et al. 2003).

Seismic lines may have a significant impact on boreal forests. Though only covering about 1% of the landscape, these narrow, linear corridors are one of the dominant anthropogenic features in Alberta's boreal forest. They are second only to cutblocks in areal extent on Alberta Pacific's Forest Industries (Al-Pac) forest management area (Al-Pac 2002). However, the ubiquitous nature of seismic lines (high numbers of lines and extensive lengths) result in their presence virtually throughout the region (Schneider 2002). Seismic lines are responsible for the vast majority of human caused edge. Seismic lines can impact boreal forest plant communities primarily by 1) direct loss and change of vegetation due to creation of line itself and 2) changes in the adjacent forested edge vegetation structure and composition due to the creation of the line. If seismic line impacts are restricted to the line itself impacts will strictly be limited to the immediate footprint which, in the future, may be eliminated with better practices. If, however, there is a change in the adjacent forested edge, the impact of seismic lines will be greatly magnified.

Seismic lines are a unique disturbance in the boreal mixedwood forest. Narrow, straight, and long disturbances do not have an analogous natural disturbance. Seismic lines are probably most similar to a canopy gap in terms of light, although they likely have more light than a gap because there are no trees on the sides of the opening casting shade during the early and later parts of the day (Groot et al. 1997). It is unlikely that light levels will further decrease over time because seismic lines have been shown to have slow reforestation (Revel et al. 1984; Osko and MacFarlane 2000) and because remaining *Populus* spp. canopy trees have narrow crowns which are unlikely to expand to fill the opening created by the line and further block light (Lieffers et al. 1999). Seismic lines are also dissimilar to natural gaps because the process of clearing seismic lines traditionally involved using bulldozers, which disturbed the ground vegetation and upper layers of soil while removing any woody debris. Understory community composition is influenced by numerous factors, including light, temperature, soil nutrient and moisture availability, dispersal limitations, competition, and herbivory (Collins and Pickett 1988; Dlott and Turkington 2000; Ehrlen and Eriksson 2000). Seismic lines may alter all these factors resulting in changes to understory plant community composition on-line.

It is difficult to make predictions about the successional trajectory of seismic lines. Understory plant community response to the seismic line may follow a similar trajectory as a cutblock or fire and progressively change in species relative abundance to a community similar to similarly-aged forest (i.e. Crites 1999). Or, like gap succession, plant communities on seismic lines may more closely resemble those of the surrounding forest due to the close proximity of intact forest and the relatively low light conditions (de Grandpre and Bergeron 1997; Kneeshaw and Bergeron 1998). However it is most likely that plant communities on seismic lines, over time, will resemble some intermediate community between an earlier successional community containing several shade-intolerant, pioneer species such as *Rubus idaeus* (Ricard and Messier 1996), *Calamagrostis canadensis* and *Epilobium angustifolium* (Lieffers and Stadt 1994) and species from the forest surrounding the seismic line that respond positively to the constant increase in light (Lieffers 1995).

Changes in environmental conditions at the forest edge can result in alteration of species composition (Murcia 1995). As physical conditions and resource availability change along the seismic line edge, species composition may also change due to differences in tolerances to the altered environment. Changes in microclimate and structure increase the temperature and amount of light at the edge (Matlack 1993; Burke and Nol 1998) resulting in increased decomposition and nutrient availability. Direct deposition of atmospheric water and nutrients is increased on edges (Weathers et al. 2001). Changes in understory species composition are generally detected in herbaceous species and young regenerating trees (Chen et al. 1992; Fraver 1994; Matlack 1994; Burke and Nol 1998; Euskirchen et al. 2001; Harper and MacDonald 2002). Understory species responses to altered microclimate conditions may immediately occur after edge creation or start after a lag period (Harper and MacDonald 2002; Matlack 1994).

Seismic line edge may not have as great an effect on species within aspen mixedwood stands due to relatively high within-stand heterogeneity in canopy cover. Aspen canopies are not as dense as coniferous forests, for example, resulting in stands that are patchy, with substantial variation in the amount of sunlight reaching the understory (Constabel and Lieffers 1996). Species within these stands may be adapted to relatively high light availability so that they are generally unresponsive to the creation of an abrupt edge. However, light varies by understory height position with most of the available light intercepted by the taller shrub and saplings before it ever reaches the herbaceous or ground layers (Constabel and Lieffers 1996; Messier et al. 1998). A vertical opening, such as an edge, may increase light to all understory strata, creating light availability patterns that are uncommon in aspen stands thereby changing understory composition.

In addition to altering communities of native plant species, seismic lines may also provide suitable habitat and corridors for non-native species dispersal to uncolonized forest (Parendes and Jones 2000). Composition of regenerating plant communities on seismic lines in Alberta's foothills forest was altered from the pre-existing community by the changes in microclimate as well as introduction of seeded plant species (Revel et al. 1984). Non-native species had spread up to 5 m into the adjacent forest over a 10 to 16 year period but did not seem to dominate or replace the native community. Corridors for powerlines in New York State, which are similar in form and function to seismic lines, had relatively high occurrence of non-native species indicating their susceptibility to colonization by non-native plants. A small component of these non-native species had also spread into the surrounding forest (Cameron et al. 1997). The authors suggested that the non-native species were maintained on the transmission line due to re-disturbance by maintenance and recreational activities. In Oregon, frequency and richness of non-native species along roads was significantly associated with higher levels of disturbance (Parendes and Jones 2000).

Non-native plant species generally do not thrive in the conditions of the interior forest due to low light and intense competition for water and nutrients (Brothers and Spingarn 1992). However, changes in edge microclimate may also increase a forest's susceptibility to establishment of non-native species populations in native forest. Edges also facilitate transport of more non-native seeds further into forest interiors (Cadenasso and Picket 2000) and colonization may be further facilitated because of greater microsite availability along edges due to tree uprooting (Esseen 1994) and availability of coarse woody debris (Harper and MacDonald 2002).

I compared the composition of understory plant communities at different times since disturbance, with particular attention to non-native species, on conventional seismic lines and on adjacent edge and interior forest to address the following questions:

1) Does succession occur on conventional seismic lines?
2) Are seismic lines on a successional trajectory towards the to interior forest plant community?
3) Are non-native species becoming more common with time?
4) Do conventional seismic lines influence the plant composition of adjacent forest edge and interior over time?
5) Are non-native species spreading into adjacent forest edges?

Recently, new seismic line construction techniques have been implemented that create seismic lines narrower (a reduction in 3m from conventional) and that minimize ground disturbance (Government of Alberta 1999). This type of seismic line is termed "low impact". I also examined the composition of understory plant communities on low impact seismic lines to assess whether newer seismic line construction techniques would:

1) Reduce the time necessary to develop plant communities similar to the interior forest or on a trajectory approaching interior forest communities.
2) Reduce edge effects relative to conventional lines.

Study area

Research was conducted in the central mixedwood subregion within the boreal forest region of Alberta (Alberta Environmental Protection 1994). This subregion falls within the Western boreal plains ecozone (Ecological Stratification Working Group 1995). This study was concentrated in upland areas where the dominant tree species is trembling aspen (*Populus tremuloides*) with balsam poplar (*P. balsalmifera*), white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*) occurring as secondary species (Alberta Environmental Protection 1994). The study region has a boreal climate with mean summer temperatures of 13.5°C and mean winter temperature of –13.2°C. Annual precipitation is 397mm, occurring mostly in the summer. Gray Luvisol soils predominate on undulating morainal plains with gleysols on wetter sites and some Eutric Brunisol soils on more xeric sites (Alberta Environmental Protection 1994). The study area encompassed three forest management units in northeastern Alberta; L1, L2 and S7. Sites were closest to the communities of Lac La Biche (55°45'N, 112'00W, ~580 m above sea level), Calling Lake (55°N, 114°W, ~640m above sea level), and Athabasca (54°43'N, 113°17'W, ~560m above sea level), respectively (Fig. 4.1).

Sample site selection

To assess the plant community response to seismic lines over time I first sampled a chronosequence of conventional seismic lines in the summer of 2001. In total, 44 seismic lines were sampled (Fig. 4.1) (Appendix 4.1). Conventional lines were categorized as young (cleared after 1988), medium aged (cleared between 1979 and 1988), and old (cleared before 1979). Sample size for each conventional line age category was 11, 8, and 12, respectively. In addition, 13 low impact seismic lines (cleared in 1996) were sampled.

Potential sites were identified with the aid of a geographic information system (GIS). Conventional seismic lines (6-8m wide with clear line of sight) were dated using two methods. First, a digital file of seismic line locations within the FMA area was acquired from consolidated provincial line data. The GIS was then used to randomly select seismic lines. Lines older than 1993 that did not have accurate digital records were aged using aerial photographs and dated to the year in which they first appeared in photographs. Lines created after 1993 and that had accurate attribute data were chosen using digital files. Low impact seismic lines were chosen using non-digital seismic program maps. All lines were cleared in 1996 because this was the earliest version of low impact seismic lines available. Lines that had been converted to a road or pipeline were rejected after field reconnaissance.

Replication was at the stand level as one seismic line could have passed through many of the desired stand types. Each line was sampled from one to three times at individual stands along the length of the line, thereby having a unique stand/line combination for each replicate site. Sample stands were dominated by aspen (*Populus tremuloides*) (>50% of canopy). Secondary species included balsam poplar (*P. balsalmifera*), white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*) in either co-dominant or sub-dominant canopy positions. Site characteristics were typical of low-bush cranberry aspen ecosites in northern Alberta (Beckingham and Archibald 1996), being well drained on level to gently sloping terrain (<15% slope) with an understory most frequently dominated by *Rosa acicularis*, *Viburnam edule*, and *Epilobium angustifolium*. Each stand was of fire origin and greater than 50 years old at the time of sampling. Sampled stands were a minimum of 1 ha in size and sites were placed to avoid any clearings, both anthropogenic and natural, by 30m or more. Doing so prevented the influence of edge from other openings on our plots. The side of the line that received the maximum amount of sunlight (i.e. south-facing) was sampled to maximize the detection of edge effects.

Regenerating tree density and cover on seismic lines in this study was low relative to other disturbance types in aspen-dominated mixedwood forests (MacIsaac and Crites 1999; Frey et al. 2003). Sapling (deciduous and coniferous) density averaged 6661 stems per ha (± 738) and sapling cover online averaged 4 % (± 0.7). Regenerating trees were generally less than 3m tall and ranged from <1 to 6.5 cm in diameter (dbh).

Sampling at each site

At each site, plots were placed on the seismic line, at the edge of the adjacent forest, and within the interior forest (Fig. 4.2). The edge of the forest was defined as the outer edge of tree trunks bordering the seismic line clearing. From the seismic line edge, a 30m transect was laid out on a compass bearing perpendicular to the seismic line orientation. This line became the centre of the site off which all plots were placed.

Abundance of each shrub species was estimated using an ocular estimate of percent cover within 2.5m by 2.5m plots. Percent cover was estimated for all forbs and dwarf woody plant species within a single 0.5m by 0.5m understory plot nested within each shrub plot. Nomenclature of vascular species followed Moss (1982). Non-vascular species were grouped as a single class and percent cover recorded. Cover was estimated from 1% increments to 10% and to the nearest 10% thereafter. Any non-native species that occurred with the nested herbaceous plot also had percent cover recorded. Non-native species were defined as species that have either been introduced to North America or were non-regional native species that have the potential to be weedy. Non-native species were identified using Weeds of Canada (Royer and Dickenson 1999) and Land and Forest Service Alberta Noxious and Restricted weeds of Alberta (Government of Alberta 2003). Northern Range Plants (Stone and Lawrence 2000) was used to identify potential non-native species contained within reclamation seed mixes.

On the cleared portion of the seismic line, spaced 2.5m apart, three nested shrub plots were sampled with one plot on the edge, another on the opposite edge, and a third directly on the centre of the line at the site's centre (Fig. 4.2). Three

2.5m by 2.5m shrub plots were placed at 0m, 4.75m, and 7.5m along the forest edge and 20m, 24.75m and 27.5m within the forest interior. These plots were offset from the centre line by 2.5m to avoid sampling trampled vegetation (Fig. 4.2).

An additional sampling technique was required for non-native species because they were expected to be very low in abundance, especially in adjacent forest communities. As with rare native plant species, non-native species are much more likely to be found by concentrating search effort over a larger area (Lancaster 2000). A constrained-area search for non-native species was performed on the line, at the edge, and in the interior forest in a total area of $100m^2$ (Fig. 4.2). On the seismic line this was the from line edge to line edge for a distance of 12.5m. Within the adjacent forest edge and interior a 10m by 10m square area was searched encompassing the nested shrub and understory plots. Occurrence of any non-native species was recorded and the position found noted (i.e. line, edge, or interior). Non-native species found within any understory plot also had abundance estimated.

Non-native species surveys were again conducted in 2002 on 30 conventional and 31 low impact seismic line sites. Comparisons were restricted to 10 year-old conventional lines (1990-1993) and 5 year-old low impact seismic lines (1993-1996) (Appendix 3.1). Sampling for non-native species at these sites was done in conjunction with vegetation structure sampling necessitating a different sampling technique that was conducted over a larger area. For a distance of 200m, 21 evenly spaced $7m^2$ circular plots (one every 10m) were searched for the presence of non-native species. A single row of plots was placed along the seismic line, with the centre of the plot at the centre of the seismic line width. Two more rows of plots were searched, one at the edge and one in the interior forest. Again, a 200m distance was covered keeping the series of plots in a straight line parallel to the orientation of the seismic line. The centre point of the row of circular plots was placed at 5m and 65m into the adjacent forest.

Data analysis

Shrub and understory data from the three plots were first combined and then the mean cover values for each species at each position (line, edge, interior) calculated. Only non-native species located within the understory plots (i.e. those with abundance estimated) were included in plant community analyses. A matrix of presence or absence of non-native plant species located in the search areas was created separately for use in multivariate analyses.

Seismic line succession

Multivariate analyses were used to examine the succession of understory communities on conventional and low impact seismic lines. I used ordination to determine whether or not plant communities on seismic lines of different ages were different and whether or not communities on old lines were similar to interior forest communities. I used a similar approach to determine if plant communities on low impact seismic lines were more similar to interior forests than conventional lines. Non-native plant species community composition was examined to determine if species composition changed over time and if composition differed on low impact seismic lines. Reductions in the presence of non-native species over time may be another indication of seismic line recovery.

Multivariate analysis was performed on understory plant community data and non-native plant species communities using PC-Ord 4.2 (McCune and Mefford 1999). Ordination was performed using non-metric multidimensional scaling (NMS) (Mather 1976). NMS was chosen because it can be used on data that are non-normal or on arbitrary or discontinuous scales (McCune and Grace 2002). With NMS the *p*-dimensional space of the original data set is reduced such that the "stress" (inverse measure of fit) is minimized in the *k*-dimensional ordination space. The analysis was run using the Sorensen distance measure, which is not influenced by outliers and is generally considered to perform well with ecological data. Dimensionality of the dataset was assessed using Monte Carlo tests, comparing the stress of each axis with stress from randomly selected data. Axes with the greatest reduction in stress (considered good if <20) and a significantly better fit than random were used. In most cases, three dimensions were used.

Evaluation of how well the ordination summarized the multivariate data was accomplished by calculating the coefficient of determination (r^2) between the distances in the ordination space and distances in the original space (McCune and Grace 2002). Graphic representation of the ordination result used the two axes with the highest r^2. Rare species were not deleted from the species matrices because deletion of rare species in preliminary analyses did not improve the fit of the ordinations to the data and rare species were often of ecological significance (i.e. non-native species).

Differences between groups (e.g. seismic line ages) were examined using multiple response permutation procedures (MRPP) (Zimmerman et al. 1985). This method again requires no assumptions regarding data normality and as such provides a reliable statistical test for observed differences in the multivariate dataset. Where appropriate, i.e. line and interior forest comparisons, the MRPP analysis was blocked by site to control for site-to-site variability (McCune and Grace 2002). To enable better comparisons between the NMS ordinations, Sorensen distance measures were used.

Edge effects

For determination of significant edge effects comparisons were made between edge communities and communities on seismic lines and in the interior. The interior and on-line communities were considered reference points. The expectation was that with no edge effect, the edge and interior communities should be readily separated from the on-line community. If there was an effect then the edge community would overlap the on-line community. Low impact seismic lines, due to narrower widths, were not expected to change conditions at the edge as severely as conventional lines. Any edge effects should be reduced in magnitude or undetectable.

I used NMS ordination and blocked MRPP to compare plant communities on seismic line edges with those on the seismic line and the interior forest.

Individual species' positive and negative response to edge effects may interact to produce no overall community effect (Murcia 1995) therefore changes in cover of common understory species were compared between the edge and the interior forest using paired t-tests. Only species with greater than 20% frequency were considered common. Species cover data was transformed using the arcsine square-root transformation to improve normality.

An additional effect of edge may be the potential spread of non-native plant species. Non-native species composition and presence was compared on the edge and in the interior forest over time to determine if non-native species were spreading into the adjacent forest. Non-native community composition was examined to determine if, in addition to presence, different groups of species were invading over time.

Results

In total, 115 species were recorded on all 44 sites (Appendix 4.2). Young, medium, and old conventional seismic lines had 73, 62, and 83 species, respectively. Low impact seismic lines had 81 species. Out of the total species, 27 were found only on the seismic lines. Approximately half of these line species were non-native or weedy species (Table 4.1). Young, medium, and old conventional seismic lines had 4, 5, and 13 on-line restricted species, respectively. Low impact seismic lines had 12 on-line restricted species. There were 7 and 5 native species restricted to edge and interior plots, respectively (Table 4.1). Young, medium, and old conventional seismic lines had 2, 1, 2 species restricted to the edge and 2, 1 and 0 species restricted to the interior forest only. Low impact seismic lines had only one species that was restricted to the edge and one in the interior.

Seismic line succession

Plant communities on different ages of conventional seismic lines were not different (MRPP, A = 0.007, p = 0.181) indicating that over time on-line communities are not changing. Figure 4.3 shows that the pattern displayed in the ordination was not related to time since clearing with line ages showing high overlap on the graph. Most sites are clustered due to shade-intolerant species such as *Calamagrostis canadensis, Vicia americana, Lathyrus ochroleucus, Lathyrus venosus, Rubus idaeus,* and *Fragaria virginina. Taraxacum officinale* also caused clustering of all ages of seismic lines.

Because there was no significant difference between line ages all samples were pooled and compared to the interior forest. Conventional seismic lines were significantly different from interior forest communities (blocked MRPP, A = 0.106, p = <0.001) (Fig. 4.4). Low impact seismic lines are also significantly different from the interior forest (blocked MRPP, A = 0.098, p = 0.001) (Fig. 4.4) and do not appear to speed recovery of seismic lines towards the plant species composition found in the interior forest. Figure 4.4 indicates that communities on low impact seismic lines are not intermediate between conventional lines and interior forest, but are generally more similar to conventional lines than interior forest.

Low impact and conventional seismic lines had high cover of *C. canadensis*, *V. americana*, *L. ochroleucus* and *L. venosus*. *C. canadensis* separates seismic lines from interior forest on axis 2 (Fig. 4.5a). *V. edule* (Fig. 4.5b), *Mitella nuda*, and *Cornus canadensis* were negatively correlated with axis 2 indicating their dominance in interior forest. Axis 1 was positively correlated with *F. virginiana* and negatively correlated with *Alnus crispa,* showing a gradient of species composition with *Alnus* dominated sites. Non-native species such as *Festuca rubra* and *Phleum pratense* were high in cover on several low impact seismic lines, they were strongly correlated with axis 1 and were responsible for the grouping of four low impact lines away from the conventional line sites. Plant communities on low impact seismic lines were significantly different from those on conventional lines (MRPP, A = 0.021, p = 0.006) likely due to the presence of additional non-native species as seen in the ordination.

Non-native species

Non-native species were frequently encountered on both conventional and low impact seismic lines (Table 4.2). Most commonly encountered was *T. offinale*, followed by *Trifolium hybridum*. Together these two species made up over 50% of the observations on the seismic lines. Other species that were moderately common, especially on the young lines, were *Cirsium arvense*, *P. pratense*, *Agropyron repens*, *F. rubra*, *Sonchus arvensis*, and *Plantago majo)*. Species that were infrequent, found only on the lines were, *Stellaria media*, *Ranunculus acris*, *Poa pratensis*, *Erysimum cheiranthoides*, and *Medicago sativa*.

Low impact seismic lines had the highest occurrence of non-native species with 92% of lines sampled having presence of a non-native plant species within the searched area (Table 4.3). Conventional lines, in total, had 61% occurrence of non-native species. Young, medium, and old conventional lines had 64%, 50%, and 67% occurrence of non-native species, respectively.

Conventional seismic and low impact seismic lines, sampled in 2002, had very high occurrence of non-native species on-line (likely due to the larger area searched); 90% of conventional lines and 97% of low impact lines sampled had presence of non-native species.

Non-native species communities sampled on conventional and low impact lines in 2001 were divided into three groups (Fig. 4.6). Axis 2 was positively correlated with *T. officinale* and *T. hybridum* and negatively correlated with *F. rubra* and *P. pratense*, generally separating conventional lines from low impact lines, respectively (MRPP, A = 0.065, p = 0.020). Non-native species communities on low impact seismic lines were further separated into two groups by axis 1, those dominated by *S. arvensis* and those dominated by *F. rubra*. There was no differentiation of non-native plant species communities on conventional seismic lines based on line age (MRPP, A = 0.047, p = 0.137).

There was no difference between non-native plant species communities on conventional and low impact seismic lines sampled in 2002 (MRPP, A = 0.015, p = 0.078), indicating that when seismic lines are sampled over a larger area most non-native plant species are found. This also indicates that differences between low impact and conventional seismic line non-native plant species communities may be less than indicated by the 2001 data.

Edge effects

To assess the potential for any changes in edge communities due to the influence of conventional seismic lines, data from all lines, edges and interiors were analysed in one ordination. Low impact seismic on-line, edge, and interior communities were analysed separately from conventional lines to better present the differences in edge influence between the low impact and conventional seismic lines.

Conventional seismic lines did not have a large effect on edge communities. Ordination of conventional seismic lines and adjacent edge and interior forest showed a small number of edge samples that were intermediate between the on-line communities and interior forest, but most edge samples were clustered with the interior forest (Fig. 4.7). In contrast, edge and interior communities were grouped quite separately from the communities on low impact seismic lines (Fig. 4.8). Edge samples did not overlap low impact seismic line samples. Low impact seismic lines may have less influence on edges than conventional seismic lines.

There were significant differences between conventional on-line, edge, and interior communities (blocked MRPP, A = 0.069, p = <0.001). Pair-wise comparisons of the on-line to the edge and interior communities were significantly different (blocked MRPP, A = 0.104 and 0.105, respectively, p<0.001 for both). The edge and interior communities were not significantly different from each other (blocked MRPP, A = 0.004, p = 0.182). Plant communities on low impact seismic lines were significantly different between on-line, edge, and interior positions (blocked MRPP, A = 0.078, p = <0.001). Pair-wise comparisons between low impact of on-line communities to the edge and interior communities were significantly different (blocked MRPP, A = 0.104 and 0.098, respectively, p<0.01 for both). Edge and interior forest communities along low impact seismic lines did not have significantly different composition (blocked MRPP, A = -0.007, p = 0.730).

Few individual species were affected by conventional seismic line edges. Four common species, *Cornus canadensis*, *M. nuda*, *Ribes triste* and *Viola renifolia* were 30-60% lower on the edge than in the interior forest (p< 0.05) (Table 4.4). *Aralia nudicaulis*, *Maianthemum canadensis*, and *Rubus pubescens* also were about 30% lower on the edges, but differences were not significant. Several common species had observably higher cover at the edge, e.g. *C. canadensis*, *Linnaea borealis*, and *F. virginiana*, but the differences between the edge and interior were far from significant.

On edges of low impact seismic lines only two species had significant declines in cover on the edge. *M. nuda* and *Mertensia paniculata* declined by 70% at the edge versus the interior forest (p< 0.05) (Table 4.5). In contrast to conventional seismic lines, there was no change in cover of *R. triste* or *V. renifolia*, whereas *Cornus canadensis* increased slightly on the edge (p>0.05). The majority of species showed a positive growth response to the edge such as, *F. virginiana*, *Galium boreale*, *V. edule*, and *M. Canadensis* (p>0.05).

Forests adjacent to seismic lines had many fewer observations of non-native species. Most observations of non-natives species on the sampled sites occurred at the edge (Table 4.2). At the edge and within the interior forest the majority of observations were of *T. officinale*. Only four additional species were found at the edge: *T. hybridum*, *A. repens*, *C. arvense*, and *P. major*. A single seismic line had an observation of *A. repens* in the interior forest.

Forests surrounding conventional lines, sampled in 2001, had 23% occurrence of non-native species on the edge in total (Table 4.3). Only 8% of low impact seismic line edges had an occurrence of a non-native species as compared to 92% on the line. As age of conventional seismic lines increased, non-native species presence on the edge seemed to increase. Young lines had 9% occurrence, medium 25% occurrence, and old lines 33% occurrence of non-native species along the edge. Young conventional lines, sampled in 2002, that had high percentages of non-native species on the line, only had 13% occurrence along the edge. Taken together, the data indicates that non-native presence along the edge starts low and increases over time. However, in contrast to this pattern of slow spread, low impact seismic lines sampled in 2001 had very high occurrence of non-native species on the edge (32% of sites).

Due to the sparseness of the non-native species matrix for edge and interior forests multivariate community analyses were not appropriate. However, some patterns of community composition were evident. The number of different non-native species on edges increased over time along with percent occurrence. Young conventional only had *T. officinale*, medium aged lines had *T. officinale* and *C. arvense*, and old conventional seismic lines had all five observed species along the edge (Table 4.2). Conventional and low impact seismic lines sampled in 2002, both young lines, primarily had only *T. officinale* along the edge. One record of *C. arvense* was along a low impact seismic line edge.

Only *T. officinale* occurred in the interior forest for all seismic line ages and types, for both sampling years. Interior forests had very few occurrences of non-native species, and penetration of non-native plant species could be considered a rare event.

Discussion

Seismic line succession

This study indicated that understory plant communities on seismic lines were very different than interior forests and they changed little up to 30 years after creation. On-line communities were unique because they included species adapted to high light and disturbance. These types of species included native species, such as *Calamagrostis canadensis* (Lieffers and Stadt 1994) and *Fragaria virginiana* (Johnson et al. 1995), as well as several non-native species, such as *Taraxacum officinale, Trifolium hybridum*, and *Cirsium arvense*, that are usually associated with agriculture (Haeussler et al. 2002; Royer and Dickenson 1999).

Understory community composition on seismic lines is similar to early successional communities on other disturbances. Young aspen cutblocks also have relatively high cover of *C. canadensis*, *Rubus pubescens* and *T. officinale* (Crites 1999). However, over a thirty-year period cutblocks developed greater dominance of shrub species resulting in more shade tolerant herbaceous species colonizing cut areas as compared to seismic lines. The addition of several non-native plant species to the seismic line community is also indicative of suspension of the community in a different state than those found on regenerating cutblocks.

The lack of recovery could be due to the lack of tree regeneration and the resulting maintenance of high light environments at the understory level. Seismic lines within aspen mixedwood forests (Osko and MacFarlane 1999) and lodgepole pine forests (Revel et al. 1984) had tree densities and growth, respectively, that were much below what would be expected for the time elapsed since clearing. These authors suggested that slow tree regeneration could be due to root damage from the original disturbance, compaction of the soil in tire ruts, insufficient light reaching the forest floor, maintenance of apical dominance from surrounding stand, and repeated disturbance on the line. Canopy tree development is considered a major determinant of the composition of understory communities (McKenzie et al. 2000). Cameron et al. (1997) found species composition of understory plant communities on maintained powerline rights-of-way was distinct from adjacent forest due to species indicative of high-light but also of moderate-disturbance habitat.

Understory composition, like tree regeneration, is also likely strongly affected by the on-line soil disturbance. The soil disturbance and compaction caused by the bulldozer while creating a seismic line may alter soil temperature, nutrients and moisture availability, affecting recruitment, growth and survival of understory species (Kozlowski 1999; Small and McCarthy 2002). Boreal forest species composition is sensitive to increasing levels of soil disturbance. Haeussler et al. (2002) reviewed eight boreal forest studies to determine the effects of post logging silviculture on species composition. As disturbance severity increased, due to various site preparation methods, the residual plant communities were replaced progressively by species regenerating from the budbank, the seedbank, and from newly dispersed seed. The result was a community shift to stress tolerant and successional generalists, at moderate disturbance, to invasive competitives and ruderals (Grime 1979) after extreme disturbance (Haeussler et al. 2002). Bell and Newmaster (2002) also found higher species richness at increasingly severe silvicultural methods due to increases in seed dispersed and exotic (ruderal) species. Seismic lines may be considered a moderate to severe disturbance in these aspen mixedwood stands because the community seems to have shifted towards species that regenerate by budbank (*C. canadensis*), seedbank (*Vicia americana, Rubus idaeus*), and newly dispersed seed (*T. offincinale* and *Cirsium arvense*) (Johnson et al. 1995; Lieffers 1995).

Low impact clearing techniques do not appear to speed the recovery of seismic lines. Low impact lines also had high cover of species adapted to light and disturbance and also had higher occurrence and variety of non-native species than conventional seismic lines. Low impact seismic lines were likely seeded with a reclamation seed mix, as was common practice since the late 1970s (Revel et al. 1984; Alberta Energy and Natural Resources 1979). Reclamation seed mixes are designed to establish high vegetative cover in a short time period to protect against erosion (Gerling 1996). Where found, *F. rubra* was generally very high in cover along the length of the sampled line, much higher cover than any other non-native species observed. Non-native species added to the dissimilarity in low impact seismic line community compared to older seismic lines. Conventional lines were also likely seeded and so these high cover non-native species are unlikely to persist. Extensive overlap in species composition between the two line types otherwise suggests that low impact seismic lines are on a similar understory community composition trajectory as conventional seismic lines.

Individual seismic lines may be subjected to bulldozer clearing one to many times after they are initially cleared (Appendix 1.1). Re-cleared lines are needed to gather additional geophysical data or are used to access a new location. Re-clearing could possibly be a confounding factor in this study. Plant communities on these four different aged lines may not be different because they had all been cleared (or re-cleared) by a bulldozer within a similar time period (i.e. the last 10 years). It is very difficult to determine if and when a line has been re-cleared, however, high cover of vegetation on all sampled lines indicated that re-clearing had not occurred recently. Some lines may have been re-cleared repeatedly but it is unlikely that all sampled seismic lines would have been re-cleared. As re-use of existing seismic lines is encouraged (Government of Alberta 1999) its effects should be considered in the pattern of seismic line succession.

Edge effects

Plant community composition along seismic line edges did not significantly differ from interior forests. Shading from tall shrubs and saplings at the edge (see Chapter 3) may have limited changes in microclimate that would result in shifts in understory species composition (Harper and MacDonald 2002). Response of individual shrub and understory species confirmed that seismic line edge effects are minimal. Only four species at the edges of conventional seismic lines had significantly different cover on the edge than the interior forest. Two of these species, *Mitella nuda* and *Ribes triste*, could be considered sensitive to edge. They were also lower in abundance at lakeshore and cutblock edges (Harper 1999). *M. nuda*, in particular, has been shown to be an interior forest obligate, avoiding edges for up to 60m (Lieffers 1995; Harper and MacDonald 2001, Harper and MacDonald 2002).

Low impact seismic lines may have less of an edge effect than conventional seismic lines. Plant community along low impact seismic line edges did not differ from the interior forest and only two species had significantly lower abundance on the edge, *M. nuda* and *Mertensia paniculata*. This further substantiates *M. nuda*'s susceptibility to changes in conditions at the edge. Because there were fewer and inconsistent edge affected species on low impact lines in comparison to conventional seismic lines I would suggest that reducing the line width successfully reduces edge effect. However, low impact lines were much younger, on average, compared to conventional seismic lines and edge effects may increase in the future if environmental conditions, such as increased light, are maintained at the edge.

Non-native plant species

Small populations of non-native plant species were established on conventional and low impact seismic lines. These species were not invasive; they did not cause changes in abundance and frequency of native species on seismic lines. Non-native plant species were likely deposited on the seismic lines 1) within seed mixes used to control erosion, 2) by indirect transportation on equipment travelling down lines, and 3) by windborne seed produced from plants in nearby agricultural areas, cutblocks, or roads. Until 2001, reclamation seed mixes contained many non-native agronomic species (Government of Alberta 2001), as evidenced by the frequency of low impact seismic lines with the presence of creeping red fescue and timothy and the overall presence of alsike clover on all line types. Prevention of restricted and noxious weed species within seed mixes only began in 2000 (Government of Alberta 2000). As conventional seismic lines aged the frequency of non-native species occurrence did not decline.

Non-native species populations on seismic lines may be maintained by, in part, by disturbance on seismic lines. Re-use and frequent traffic not only provide establishment sites for non-native species but also may bring species on the tires of All Terrain Vehicles (ATVs), trucks, and equipment. This may increase the chance of establishment (Hobbs and Huenneke 1992). Increasing silvicultural disturbance provided opportunities for the establishment of non-native species in cutblocks (Bell and Newmaster 2002). High disturbance roadsides were up to 60 times more likely to have occurrence of non-native species (Parendes and Jones 2000).

Light is also considered a limiting factor for establishment and spread of exotic species (Brothers and Spingarn 1992; Honnay et al. 2002). Non-native species found on roadsides, trails, and streams were 25 times more likely to be found in high light environments (Parendes and Jones 2000). Disturbance of the forest floor caused germination of a non-native species, but all seedlings died due to inadequate light beneath the forest canopy (Cid-Benevento 1987). It is possible that increased light on the seismic line is the driving factor that maintains these populations. High richness and frequency of exotic species on low impact seismic lines indicates that the decrease in width does not reduce light to a sufficiently low level to control non-native species occurrence.

Forests adjacent to seismic lines had many fewer observations of non-native species. Trends in occurrence of non-native species along seismic line edges indicated that there might be an interaction between time since clearing and the spread of non-natives. As seismic lines aged, non-native species were more commonly observed along the adjacent forest edge. However, spread of non-native species, other than dandelion, was generally restricted in depth. Penetration distance of non-natives into older edges bordering agriculture is also quite small. Distance of spread into the adjacent forests range from 2m to 10m (Brothers and Spingarn 1994; Honnay et al. 2002; Gelhausen et al. 2000; Burke and Nol 1998; but see Fraver 1994). More recent cutblock edges do not seem to have non-native species invading (Euskirchen et al. 2001; Harper and MacDonald 2002) although populations may thrive in the conditions of a cutblock (Bell and Newmaster 2002). The process of spread from a seismic line source population would naturally be slow due to biological and environmental barriers such as poor dispersal and unsuitable light and moisture levels in interior forests (Johnstone 1986). Agricultural edges in these studies are generally decades old and have had time to overcome some barriers to non-native species spread as compared to cutblocks, indicating the importance of time since edge creation.

T. officinale was the only species commonly found more than 10m into the interior forest surrounding seismic lines. All occurrences of dandelions in the adjacent forest corresponded with occurrence of dandelions on the seismic line passing through that particular stand. However, distance spread off of the line was not consistent. There were independent observations occurring at the edge and in the interior forest. Rather than a steady invasion off a seismic line, *T. officinale* propagules may be randomly dispersing not only from seismic lines, but also from roads, cutblocks, or fields in the study area. Seeds in the interior forest may opportunistically wait for an establishment site to become available. Many occurrences of *T. officinale* in the interior forest were along ephemeral streams and/or animal trails (personal observation).

Conclusions

Lack of change in plant communities on seismic lines may indicate that direct management activities are required to return the seismic line footprint to a natural successional trajectory. Recovery techniques may include line-by-line silvicultural preparations (e.g. to ease compaction and break up grass competition) as well as tree planting, however they are likely unfeasible on the scale needed in northern Alberta. Large-scale disturbances that overlap many seismic lines, such as fire and harvest, should be evaluated for their ability to reset the seismic line succession trajectory. A key determinant of the success of overlapping disturbances will be tree regeneration on seismic lines.

Non-native species eradication may require line-by-line removal of non-native species populations before disturbances are combined. Anthropogenic disturbance in Alberta's boreal forest is relatively recent and the presence and spread of non-natives species may increase in the near future. Populations of non-native species can persist in low frequencies for long periods of time before beginning an expansion phase initiated by increased disturbance (Parendes and Jones 2000). Interactions between different disturbances may have synergistic effects that increase the rate of spread (Hobbs and Huenneke 1992). My study examines the occurrence and spread of non-natives off of only one landscape feature in northeastern Alberta and to my knowledge no other study has looked specifically at non-native species spread within the boreal forest. The question of how landscape-scale patterns of all industrial and natural disturbances might interact to influence non-native plant species spread remains unanswered. Arrangement and connectivity of linear corridors, such as seismic lines and roads, and intersecting disturbances, such as cutblocks and fires, may contribute to landscape scale spread of non-native species.

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Table 4.1. Understory plant species recorded on conventional and low impact seismic lines that were found only on the seismic line, along the edge, or in the interior forest plots.

Seismic line	Edge	Interior
Native Species		
Achillaea sibirica	*Lycopodium obscurum*	*Clematis* spp.
Agropyron trachycaulum	*Moneses uniflora*	*Geocaulon lividum*
Betula occidentalis	*Orthilia secunda*	*Habenaria obtusata*
Caltha palustris	*Symphorocarpus occidentalis*	*Lonicera villosa*
Carex spp.	*Smilacina stellata*	*Pyrola virens*
Cerastium nutans	*Ribes hudsonianum*	
Geum aleppium	*Ranunculus lapponicus*	
Geum macrophyllum		
Geum rivale		
Halenia deflexa		
Heracleum lanatum		
Hieracium umbellatum		
Koeleria cristata		
Polytrichum piliferum		
Polytrichum strictum		
Rhinanthus borealis		
Non-native or weedy species		
Agropyron repens		
Erysimum cheiranthoides		
Festuca rubra		
Phleum pratense		
Plantago major		
Poa pratense		
Potentilla norvegica		
Ranunculus acris		
Sonchus arvensis		
Stellaria longifolia		
Trifolium hybridum		

Table 4.2. Total number of seismic lines at which each non-native species occurred on the line and off of the line. In 2001 a total of 44 seismic lines were sampled on-line and 30m into the adjacent forest. In 2002, a total of 61 seismic lines were sampled on-line and into the adjacent forest. Both years, conventional and low impact seismic lines are combined.

Species[1]	2001			2002		
	On-line	Edge	Interior	On-line	Edge	Interior
Taraxacum officinale	24	3	2	51	13	11
Trifolium hybridum	17	1	-	22	-	-
Phleum pratense	5	-	-	11	-	-
Agropyron repens	7	2	-	6	-	-
Cirsium arvense	6	2	-	15	1	-
Festuca rubra	4	-	-	9	-	-
Plantago major	3	1	-	13	-	-
Sonchus arvensis	4	-	-	9	-	-
Erysimum cheiranthoides	1	-	-	-	-	-
Stellaria longifolia	1	-	-	-	-	-
Ranunculus acris	1	-	-	-	-	-
Poa pratensis	2	-	-	3	-	-
Medicago sativa	-	-	-	1	-	-

Table 4.3. Percentage of seismic lines sampled that had non-native plant species occurring on the line, along the edge and in the interior forest.

Year Sampled	Line Type	Year Cleared	n	Line	Edge	Interior
2001	Low Impact	1996	13	92	8	8
	Conventional	after 1988	11	64	9	0
		1979 to 1988	8	50	25	0
		before 1979	12	67	33	8
2002	Low Impact	1996	31	97	32	32
	Conventional	after 1988	30	90	13	3

Table 4.4. Mean cover for all common understory species (> 20% frequency) found on the edge and interior of conventional seismic lines. Edge and interior means were compared using paired t-tests (alpha = $p < 0.05$). Significant values are bolded. Data are means ± SE.

Species	Edge	Interior	t	*p*
Alnus crispa	5.5 ± 1.8	7.0 ± 2.5	-7.600	0.453
Alnus tenufolia	0.7 ± 0.5	1.1 ± 0.7	-0.527	0.602
Amelanchier alnifolia	0.7 ± 0.3	1.0 ± 0.4	-1.139	0.264
Aralia nudicaulis	4.7 ± 0.9	7.6 ± 1.3	-1.776	0.086
Aster ciliolatus	2.3 ± 0.9	1.7 ± 0.5	0.393	0.697
Aster conspicuus	0.9 ± 0.4	0.5 ± 0.2	0.953	0.348
Calamagrostis canadensis	7.9 ± 1.6	7.1 ± 1.9	1.040	0.307
Cornus canadensis	**3.1 ± 0.7**	**4.6 ± 0.8**	**-2.112**	**0.043**
Cornus stolonifera	1.0 ± 0.5	1.1 ± 0.8	0.302	0.764
Epilobium angustifolium	2.0 ± 0.4	2.4 ± 0.9	0.752	0.458
Equisetum pratense	0.4 ± 0.2	0.0 ± 0.0	1.768	0.087
Equisetum arvense	0.5 ± 0.2	0.1 ± 0.1	1.633	0.113
Fragaria vesca	0.7 ± 0.3	0.5 ± 0.2	0.329	0.744
Fragaria virginiana	1.1 ± 0.4	0.8 ± 0.3	0.449	0.657
Galium boreale	1.1 ± 0.3	0.8 ± 0.2	0.523	0.605
Galium triflorum	0.2 ± 0.1	0.3 ± 0.2	-1.224	0.231
Lathyrus venosus	0.5 ± 0.2	0.7 ± 0.3	-0.919	0.366
Linnaea borealis	3.3 ± 1.5	2.6 ± 0.6	-0.335	0.740
Lonicera dioica	0.8 ± 0.3	0.8 ± 0.5	0.608	0.548
Lonicera involucrata	4.4 ± 1.2	3.7 ± 1.0	0.819	0.819
Maianthemum canadense	1.0 ± 0.2	1.4 ± 0.3	1.459	0.155
Mertensia paniculata	1.3 ± 0.4	1.1 ± 0.4	0.189	0.852
Mitella nuda	**2.5 ± 0.5**	**4.1 ± 0.8**	**-2.665**	**0.012**
Petasites palmatus	1.3 ± 0.5	1.3 ± 0.4	-0.298	0.767
Pyrola asarifolia	0.6 ± 0.2	0.5 ± 0.1	-0.346	0.732
Ribes oxyacanthoides	2.3 ± 0.8	1.8 ± 0.5	0.441	0.662
Ribes triste	**1.0 ± 0.2**	**1.5 ± 0.3**	**-2.369**	**0.024**

Table 4.4. (continued)

Rosa spp.	5.9 ± 0.8	6.8 ± 0.9	1.282	0.210
Rubus idaeus	2.9 ± 0.8	1.9 ± 0.6	0.999	0.326
Rubus pubescens	2.4 ± 0.4	3.5 ± 0.5	-1.863	0.072
Salix spp.	0.8 ± 0.3	0.7 ± 0.5	1.144	0.262
Symphoricarpos albus	1.6 ± 0.6	2.5 ± 0.9	-1.024	0.314
Viburnum edule	6.4 ± 0.9	7.3 ± 0.9	-0.828	0.414
Vicia americana	0.2 ± 0.1	0.1 ± 0.1	0.314	0.756
Viola adunca	0.2 ± 0.1	0.0 ± 0.0	1.438	0.161
Viola canadensis	0.5 ± 0.2	1.1 ± 0.5	-0.876	0.388
Viola renifolia	**0.2 ± 0.1**	**0.5 ± 0.2**	**-2.242**	**0.032**

Table 4.5. Mean cover for all common understory species (> 20% frequency) found on the edge and interior of low impact seismic lines. Edge and interior means were compared using paired t-tests (alpha = p< 0.05). Significant values are bolded. Data are means SE.

Species	Edge	Interior	t	*p*
Alnus crispa	0.3 ± 0.3	0.5 ± 0.3	-0.779	0.457
Amelanchier alnifolia	1.0 ± 0.5	1.6 ± 0.8	-0.691	0.503
Aralia nudicaulis	12.0 ± 4.6	10.6 ± 4.3	0.629	0.541
Aster ciliolatus	2.4 ± 0.6	1.9 ± 0.7	1.156	0.270
Aster conspicuus	1.8 ± 1.0	1.4 ± 0.9	0.374	0.715
Calamagrostis canadensis	2.7 ± 0.7	2.1 ± 1.0	0.745	0.471
Cornus canadensis	5.9 ± 0.8	4.9 ± 1.0	1.088	0.298
Epilobium angustifolium	4.4 ± 2.1	4.0 ± 1.4	0.069	0.946
Fragaria vesca	1.2 ± 0.6	1.5 ± 0.6	-0.557	0.588
Fragaria virginiana	1.4 ± 0.5	0.3 ± 0.1	2.002	0.068
Galium boreale	1.6 ± 0.4	0.9 ± 0.3	1.370	0.196
Lathyrus ochroleucus	0.7 ± 0.4	0.6 ± 0.2	-0.210	0.838
Lathyrus venosus	2.8 ± 1.1	2.0 ± 0.8	0.475	0.643
Linnaea borealis	5.6 ± 2.0	4.7 ± 2.1	0.545	0.596
Lonicera dioica	0.4 ± 0.1	0.3 ± 0.1	0.926	0.372
Lonicera involucrata	0.2 ± 0.1	0.1 ± 0.1	0.871	0.401
Maianthemum canadense	2.0 ± 0.5	1.4 ± 0.3	1.331	0.208
Mertensia paniculata	**0.6 ± 0.4**	**1.9 ± 0.6**	**-3.420**	**0.005**
Mitella nuda	**0.4 ± 0.2**	**1.6 ± 0.5**	**-2.547**	**0.026**
Petasites palmatus	1.3 ± 0.4	2.0 ± 0.6	-1.139	0.277
Pyrola asarifolia	0.5 ± 0.2	0.8 ± 0.3	-0.739	0.474
Ribes triste	0.5 ± 0.2	0.4 ± 0.2	0.695	0.500
Rosa spp.	5.5 ± 0.9	5.6 ± 1.1	0.348	0.734
Rubus idaeus	0.3 ± 0.2	0.5 ± 0.2	-1.077	0.303
Rubus pubescens	3.4 ± 1.0	3.9 ± 1.1	-0.251	0.806
Salix spp.	0.6 ± 0.3	0.6 ± 0.2	-0.166	0.871
Symphoricarpos albus	0.4 ± 0.2	0.3 ± 0.2	0.300	0.769
Viburnum edule	3.8 ± 1.4	2.4 ± 1.0	0.915	0.378
Vicia americana	0.4 ± 0.3	0.2 ± 0.1	0.914	0.617
Viola canadensis	0.3 ± 0.2	0.1 ± 0.0	0.791	0.444
Viola renifolia	0.2 ± 0.1	0.3 ± 0.2	0.289	0.777

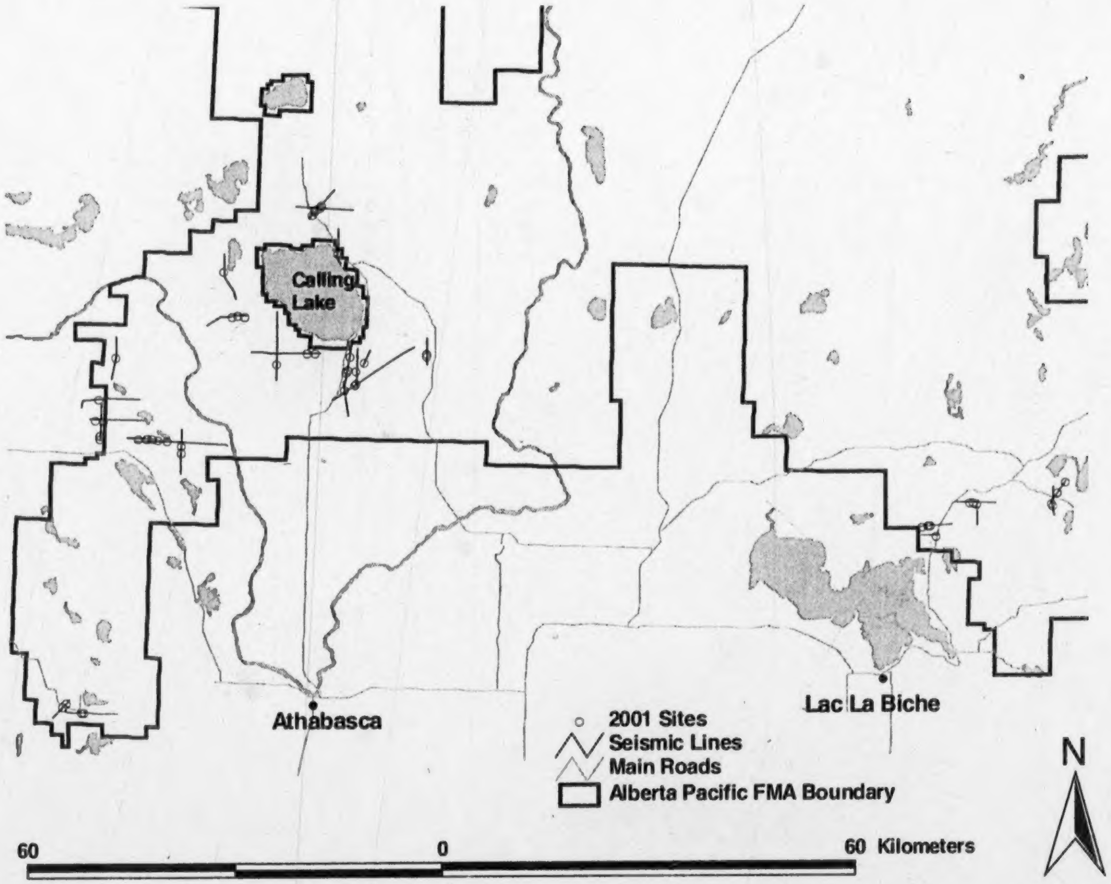
Calling Lake
Athabasca
Lac La Biche
2001 Sites
Seismic Lines
Main Roads
Alberta Pacific FMA Boundary
60
0
60 Kilometers
N

Figure 4.1. Locations of sites sampled in 2001 on both conventional and low impact sites.

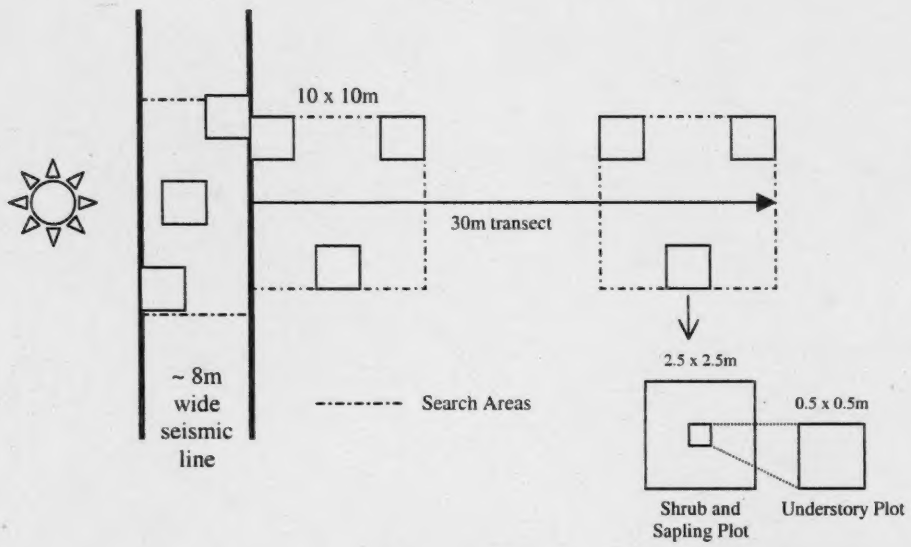
10 x 10m
30m transect
~ 8m wide seismic line
Search Areas
2.5 x 2.5m
0.5 x 0.5m
Shrub and Sapling Plot
Understory Plot

Figure 4.2. Each site consists of three 2.5m x 2.5m shrub plots placed on the seismic line, within the adjacent forested edge, and within the interior forest. Within each plot is a 0.5m x 0.5m herbaceous understory plot. In addition, a larger area $100m^2$ area surrounding the nested plots was searched for non-native plant species. On the edge this area was 12.5m x 8m (width of line) and within the edge and interior forest this area was 10m x 10m.

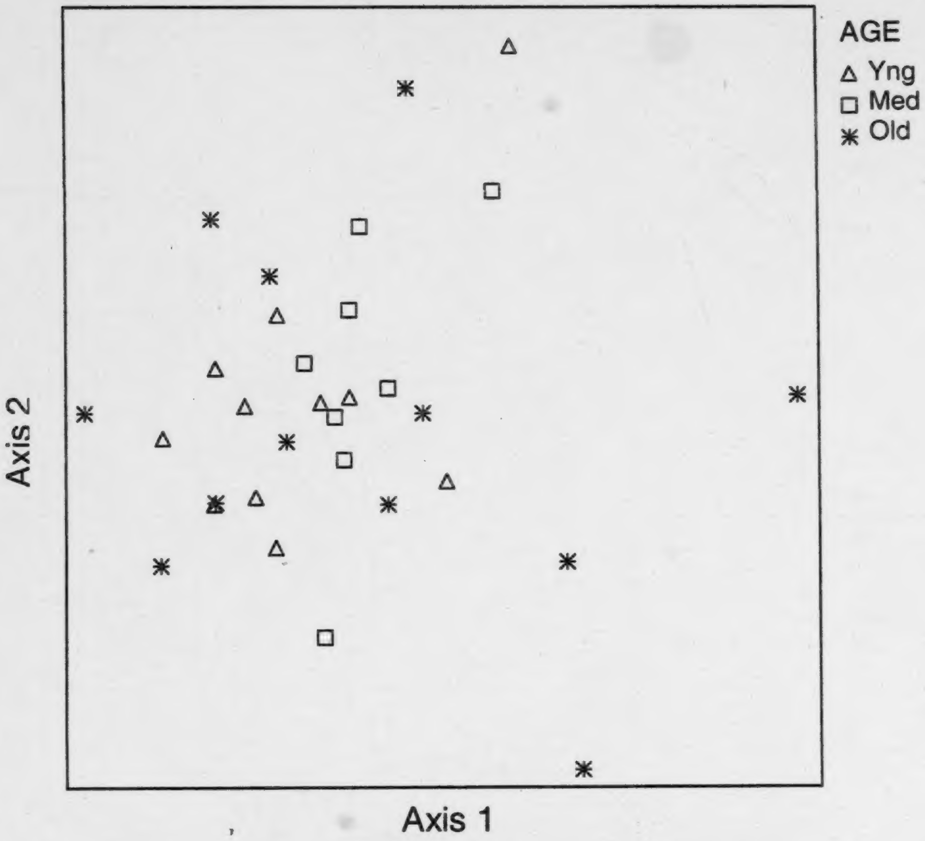

Figure 4.3. NMS ordination results on seismic line communities overlayed with seismic line age. Symbols represent young (△), medium aged (□), and old (✳) conventional seismic lines. Axis 1 and axis 2 represent 33% and 32% of the variation, respectively.

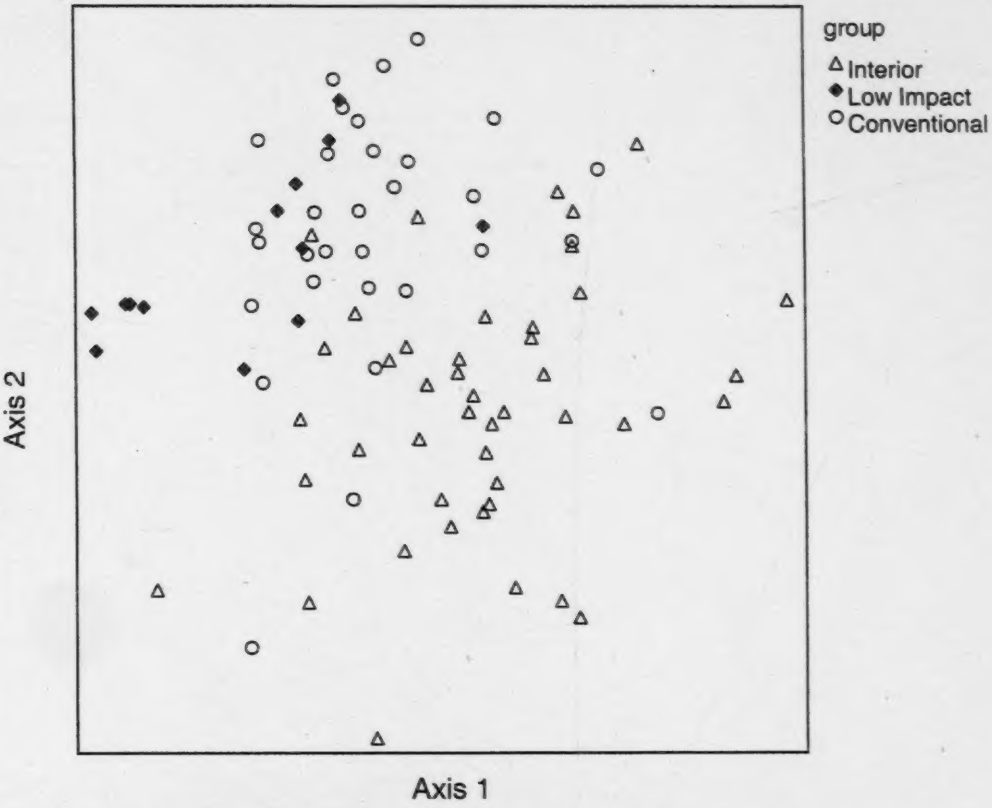

Figure 4.4. NMS ordination of conventional (○) and low impact (◆) seismic line communities and the interior forest (△) community. Axis 1 and 2 represent 29% and 24% of the variation, respectively.

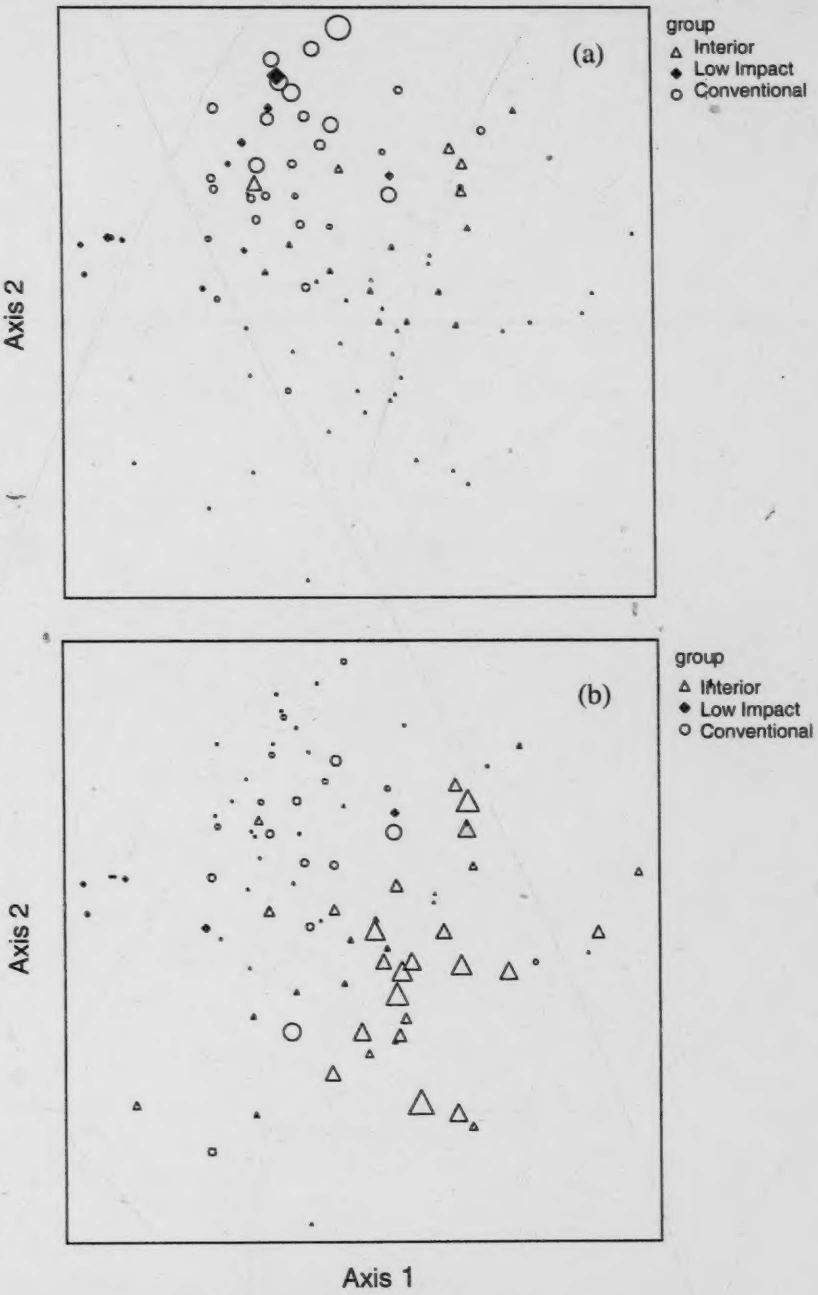

Figure 4.5. NMS ordination of conventional (○) and low impact (◆) seismic line communities and the interior forest (△) community. This is the same ordination as Fig. 4.5 but the symbols are scaled to the relative abundance of (a) *Calamagrostis canadensis* and (b) *Viburnum edule*. Larger symbols indicated higher cover at those sites.

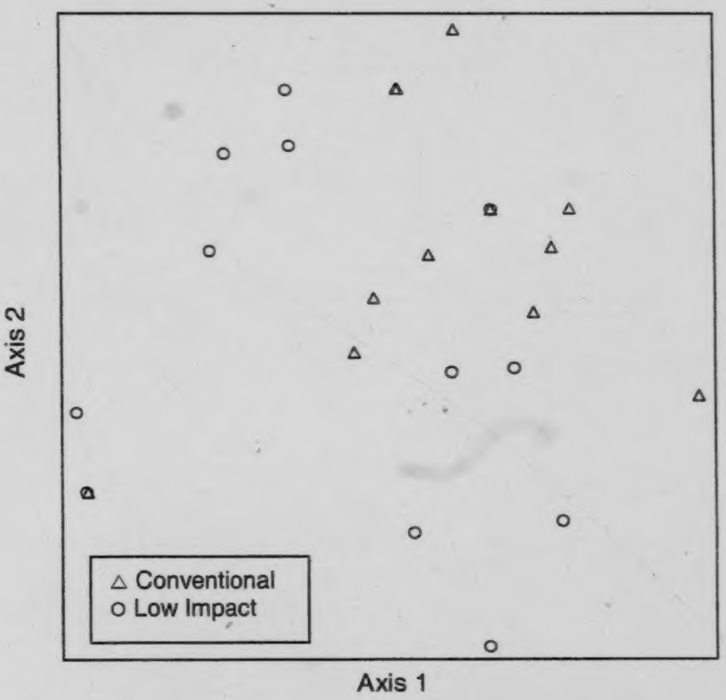

Figure 4.6. NMS ordination of non-native plant species (presence or absence) on conventional (△) and low impact (○) seismic lines. Only sites with presence of a non-native species are included in analysis. Axis 1 and 2 represent 38% and 50% of the variation, respectively.

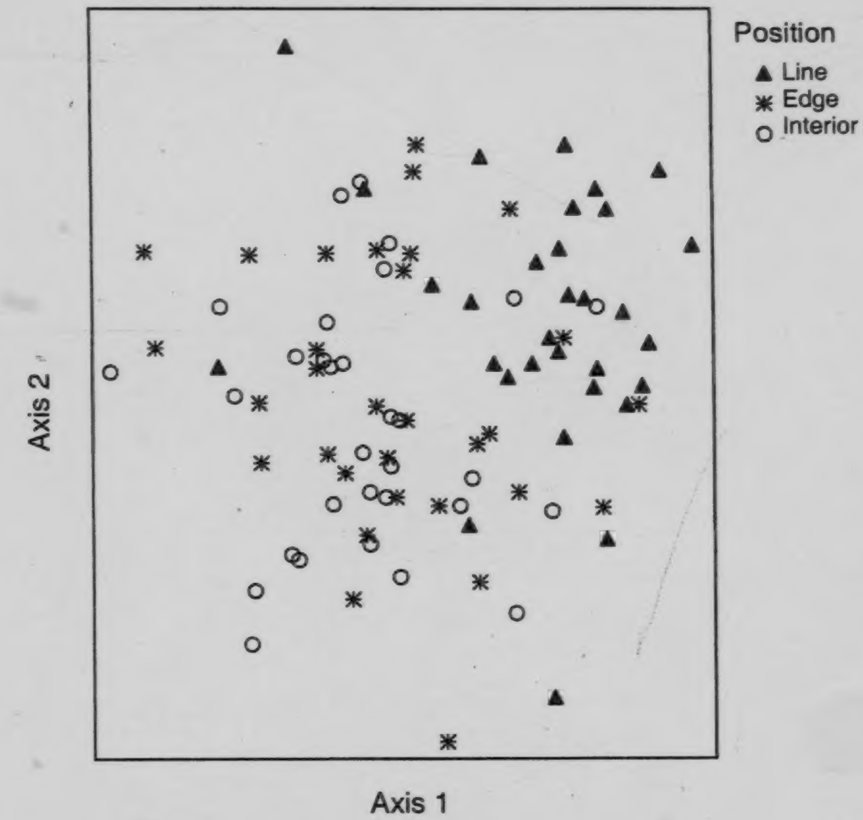

Figure 4.7. NMS ordination of understory plant communities on conventional seismic lines of all ages (▲), along edges (✱), and within the interior forest (○). Axis 1 and 2 represent 32% and 23% of the variation, respectively.

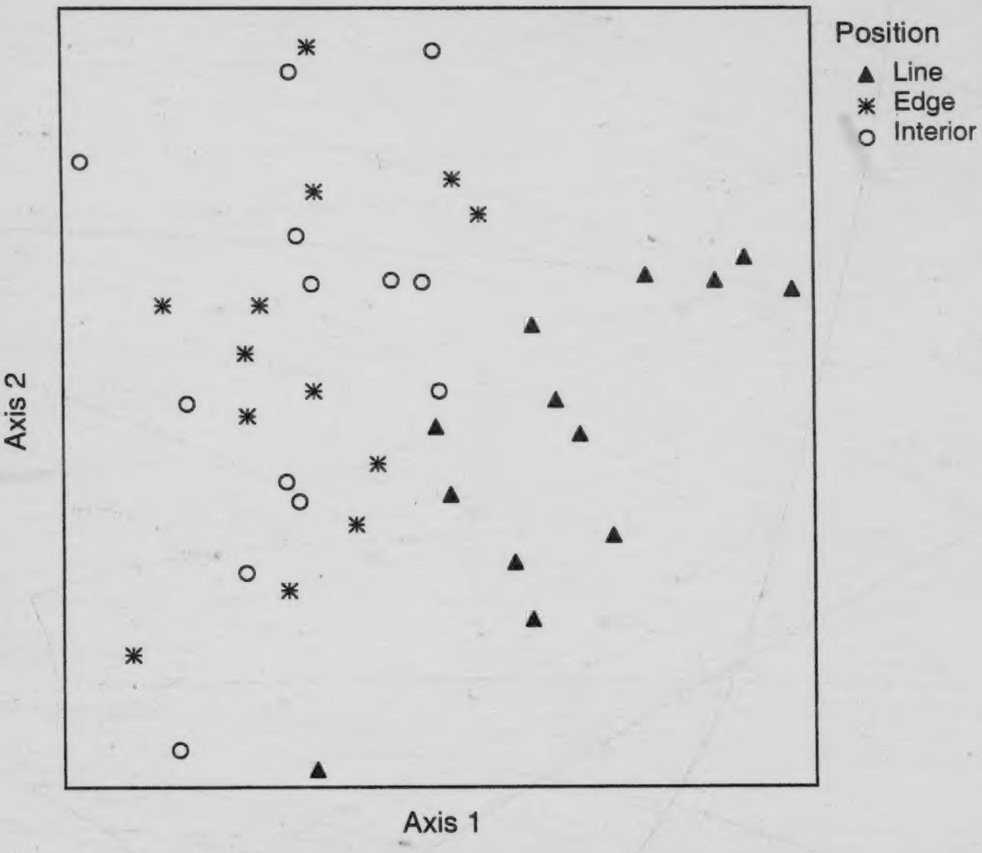

Figure 4.8. NMS ordination of understory plant communities on low impact seismic lines (▲), along the edge (✱) and within the interior forest (○). Axis 1 and 2 represent 39% and 27% of the variation, respectively.

CHAPTER 5.
GENERAL CONCLUSIONS

Thesis conclusions

In this study I have demonstrated that seismic lines impact boreal forest vegetation structure and composition primarily by increasing productivity at adjacent forest edges and by altering the composition of plant communities established on seismic lines. Specific conclusions from this research are listed below for each chapter (letters correspond to objectives listed in chapter 1).

In chapter 3, I compared vegetation structure along the edge and interior of seismic lines. My findings were:

A. Seismic lines had an effect on adjacent forest edge structure. These effects were restricted to increases in tree growth, recruitment, and vertical shrub cover. Tree mortality did not increase on seismic line edges.

B. Both conventional and low impact seismic lines had increased growth, recruitment, and shrub cover on edges. However, the magnitude of effect differed between the line types. Edges of conventional seismic lines had greater annual tree growth rates, larger increases in sapling density, and greater visual obstruction cover relative to low impact seismic lines. However, there may have been more snag blowdown and damage at the edge of low impact seismic lines relative to conventional lines.

In chapter 4, I examined the composition of the plant community on seismic lines and in adjacent forests over time. My findings were:

A. Plant communities on seismic lines were very different from interior forests and they changed little up to 30 years. Seismic lines had communities dominated by grass and other shade-intolerant, disturbance adapted species.

B. Plant communities adjacent to seismic lines were unchanged. However, a few susceptible species had lower cover at the seismic line edge compared to the interior forest.

C. Seismic lines had persistent communities of non-native plant species that were slowly spreading into the forest edge. Only dandelions were found in the interior forest.

D. Low impact seismic lines clearing techniques did not speed recovery of plant communities. Lines were dominated by grass and non-native species were common. Low impact lines did not cause changes in adjacent edge communities.

Implications

This study confirmed that seismic lines do have impacts on aspen mixedwood forest vegetation structure and composition. Lack of recovery of undertstory plant communities coupled with slow tree regeneration (Osko and MacFarlane 1999) on conventional seismic lines indicates that the immediate seismic line footprint may be very long-lasting. Conventional seismic lines should not be considered restored to natural aspen mixedwood forest for at least 25 years. Low impact lines do not provide an immediate improvement in plant community composition although the length of time for restoration to natural plant communities is unknown.

Although non-native species were not found to be a significant component of the on-line or edge communities presently, seismic lines may cause spread of non-native species to other areas of the boreal forest where populations may become more invasive. Populations of non-native species can persist in low frequencies for long periods of time before beginning an expansion phase initiated by increased disturbance (Parendes and Jones 2000). Future increases in amount and connectivity of linear corridors, such as seismic lines and roads, and intersecting disturbances, such as cutblocks and fires, may contribute to landscape-scale spread of non-native plant species (Hobbs and Huenneke 1992).

The findings of this study may have several implications for wildlife. Primarily, the very slow recovery on seismic lines has direct implications for total available habitat area if some species are not including seismic lines as part of their overall habitat area (ovenbirds, E.M. Bayne unpublished data) or are avoiding seismic lines due to human or predator use of lines as travel corridors (caribou, Dyer et al. 2001). Edge effects, such as increased sapling density and shrub cover, may result in changes in species abundance and distribution on edges. Increased cover and vertical structure along the edge may have effects on birds (Wilson 1974), potentially increasing the species in a forest patch that would use seismic line edges as nesting and foraging habitat (Gates and Gysel 1978; Kroodsma 1982). Predation and parasitism of songbird nests are generally not concerns on seismic line edges in the boreal mixedwood forest (Song and Hannon 1999).

Other vertebrate species may also be attracted to these high cover edges for foraging (Hansson 1994). Rodent abundance was highest under high shrub cover along edges and corresponded to increased seed predation (Kollman and Buschor 2002). Increased downed woody material along seismic lines due to industrial practices may also alter movement and distribution of species that use downed wood for foraging, transportation, and thermoregulation (Harmon et al. 1986).

Low impact seismic lines are an improvement over conventional seismic lines in terms of edge effects and reduction of total area cleared. However, plant community restoration rate, presence of non-native plant species, and tree regeneration (A. MacFarlane unpublished data) are not significantly improved in comparison to conventional lines. Low impact lines are a good alternative to conventional lines but other line types should be evaluated for their ability to further reduce the area cleared as well as minimizing changes to plant communities and tree recovery rates.

Negligible seismic line edge effect may not contribute significantly to negative ecological (effective habitat) or economic (tree volume loss) cumulative effects. However, the increasing seismic line footprint (Appendix 1.1) poses significant risks to ecological integrity and timber supply. Management of the geophysical exploration footprint should focus on: a) adoption of best practices, such as mulcher-cut, hand-cut, and heliportable seismic lines that can create lines less than 2.5m wide (techniques already common in more "high-profile" regions such as the eastern slopes of the Rocky Mountains), and b) aggressive reclamation or reforestation of existing seismic lines, including strategic management of the practice of re-clearing lines. Seismic lines will not have opportunity to regenerate, naturally or by human intervention, if they are continually redisturbed.

The cumulative impact of industrial development is expected to rapidly alter the once contiguous forested landscape into a forest reduced in extent and one that is increasingly fragmented. Seismic lines should be considered in conjunction with all human disturbance on the landscape and meaningful targets and thresholds set to maintain the ecological and economic sustainability of northeastern Alberta. Alberta is experiencing levels of linear development unprecedented in forested regions worldwide, and preliminary research indicates that significant changes in biota are occurring in the most heavily impacted sites (Schneider et al. 2003). Narrow seismic lines and the implementation of seismic line restoration and reduced access (recreation and industrial) are already guidelines put forward in a strategic plan for woodland caribou conservation in Alberta (Boreal Caribou Committee 2001). These guidelines should be implemented throughout the boreal forest region using the framework outlined for industry in the Athabasca oil sands region (Lormel Consultants and AXYS Environmental Consultants 2002).

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APPENDIX 1.1
RELATIVE AMOUNTS OF REDUCED WIDTH SEISMIC LINES IN ABERTA-PACIFIC FOREST INDUSTRIES FMA.

Introduction

Alberta-Pacific Forest Industries Inc. maintains a spatial record of all seismic lines on their Forest Management Agreement (FMA) Area. This database was created and is maintained by Evergreen Consultants (for more information contact GIS services, Alberta-Pacific). The database includes spatial location of the line and the associated attribute data also details the length of each line, the line type, company name and the year the line was cut. However, only the line length is consistently recorded. In recent years, Evergreen has been maintaining more detailed information on the type and width of seismic lines being cut. I attempted to use these data to examine the relative amount of low impact and narrow seismic lines being cut in the boreal region of northeastern Alberta.

Methods

The spatial database covered the region, north to south, from the 25th to the 16th baselines and, east to west, from the 4th meridian to range 15 west of the 5th meridian. A total of 116,370 records of individual seismic lines were entered but most had neither an associated date nor a description of the line width. Therefore, I first selected only lines with reference to the type or width of line from the database. As it turned out this subset of lines only included those created in 1993 or later. A total of 32,488 lines were selected.

All selected lines came with a government issued GEO Number, which was used as a reference number when the program application was submitted. I used the GEO number to assign an approximate year of line clearing rather than use the date info that came with the database. The numbers often agreed, however the format of the dates were not consistent and difficult to sort by.

Lines were coded first by width: (1) No width (These lines were likely conventional given that there were only two other conventional for the year with no width assigned to the lines.), (2) Conventional were lines greater than or equal to 6m in width, (3) Low impact seismic (LIS) were lines between 5.99m and 4.5m, (4) narrow lines had widths between 4.49m and 3m (5) hand or mulcher-cut lines were less than 3m wide. Secondly, lines were coded by type, either (1) new cut or (2) a re-cut of an existing line. Only lines that were newly cut were used in the analysis.

The total length of lines was used to calculate the relative percentage of lines that were conventional, LIS, narrow, or hand-cut/mulched for each year since 1993. Values from 2002 were excluded as the dataset was not complete.

The median value of each width category multiplied by the length was used to calculate the approximate area cut for each seismic line type per year. These values were summed to determine the amount of new seismic being cut annually since 1993.

Total length of reduced width lines (ie. LIS and narrow) was contrasted to the total length of seismic lines in the FMA calculated from the original complete database.

Results

Average kilometres of new lines cut per year since 1993 is 1279km (Table 1). The amount of LIS initially increased from 20% to 90% but has, in recent years, fallen to about 50% of the new lines being cut (Fig. 1). As the relative proportion of LIS being cut decreased both types of narrower lines increased to make up the remaining 50% of lines cut. Lines less than 3m in width had the greatest increase in proportion however were still less abundant than the 3 to 4.5m wide lines on the landscape with the exception of 2000. Overall, 38.6% of lines created since 1993 could be considered low impact and another 51.1% of lines are of even further reduced width. However, this is a very small percentage of the total seismic line footprint on the landscape. All reduced width lines combined represent only 4.38% of the total length of seismic lines currently on the landscape.

Despite the overall reductions in line width there was not a reduction in total area cleared (Fig. 2). In the years with the highest proportions of narrow lines, 2001 in particular, there were large amounts of area cleared strictly due to the intensity of activity. Despite some reductions in activity between 1997 and 1999 there seems to be an overall trend of increasing area cleared annually in this region. Average area cut in the last nine years is 550 ha per year.

Discussion

From these data there seemed to be rapid implementation of low impact and narrow techniques across Al-Pac's FMA. Indeed, there appears to be little to no use of conventional techniques in recent years. However, there has not been a complete shift from the first inception of low impact (i.e. average of 5m) to very narrow or hand-cut lines.

It seems apparent that a combination of reduction in activity and a narrow width is needed to reduce the amount of area cleared for geophysical exploration in the boreal forest of northeastern Alberta. There seems to have been some variation in the intensity of activity in the past but it is unlikely that seismic activity will slow down because development of future oilsand reserves requires much more intensive seismic surveys compared to conventional oil and gas. The use of 3D seismic programs is likely the driving factor behind increases in the use of narrow seismic lines and in the increase in total length cut in recent years. As for reducing width, it is promising that the use of the narrowest (< 3m) seismic is increasing.

In calculating the landscape area cleared by seismic lines accurate width data is important. Width on conventional lines varies little due to their simple linear design so we can be somewhat confident in the estimated value. However, the meandering manner of LIS lines creates considerable variation in width along the length of the line. Curves may have widths up to 2m greater than the straight portions of the line. This results in average widths that are larger than what is reported (Don Pope pers. comm. and see chapter 3). In addition, the curved line has a longer length than a straight line. Unfortunately, it is not assured that a 5m (average) line can truly avoid merchantable trees, so reduction in cut timber may not be as significantly reduced as is widely believed until use of narrow seismic is completely implemented.

It is also important to note that I have only reported figures for newly cut lines and that each year existing lines are re-opened for additional geophysical exploration. In a given year up to 30% of the length cut may be on existing seismic lines (Fig. 3; Schneider 2002). Presently, there is no regulation of width on re-opened seismic lines (Don Pope pers. comm.). Therefore, conventional lines are still being used and, as LIS become more widespread, reduced width lines may be widened in future operations.

Table 1. Total length (km) of new cut seismic lines, by year, since 1993.

Year	Length (km)
1993	669.04
1994	1131.1
1995	1401.7
1996	1415.5
1997	648.8
1998	529.6
1999	1128.7
2000	1675.9
2001	2911.1
Total	11511.44

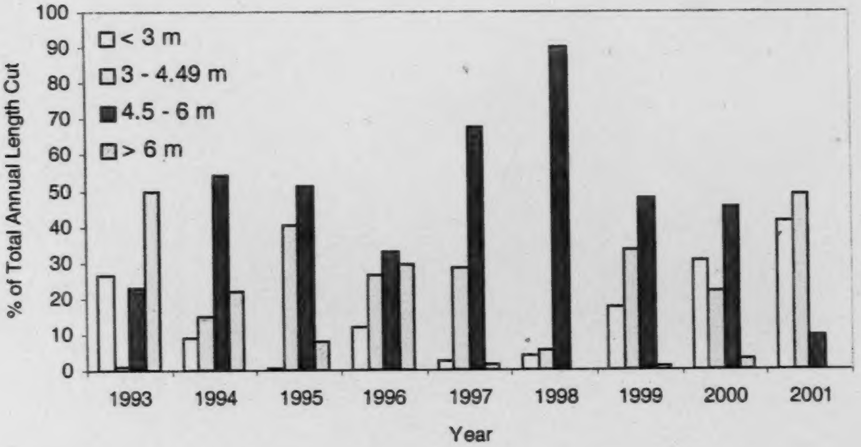

Figure 1. Percentage of total length cleared each year using conventional, low impact and narrow seismic line techniques.

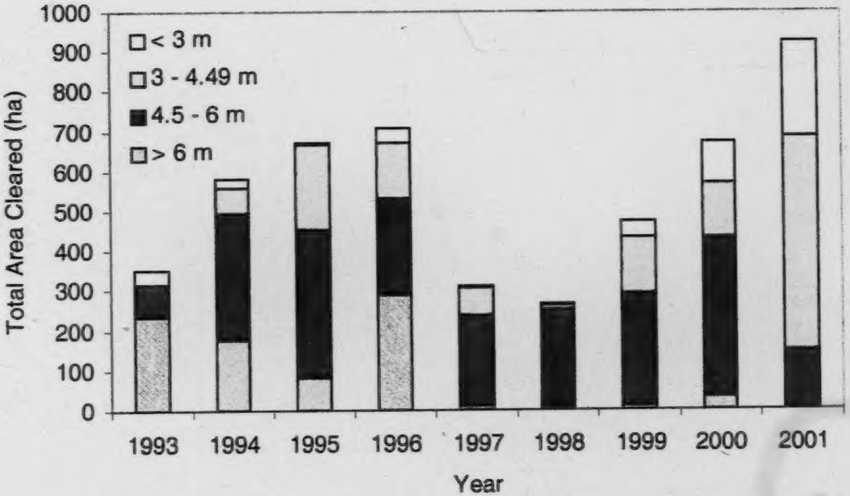

Figure 2. Total area, in hectares, of newly cut seismic lines created each year using conventional, low impact, and narrow seismic line techniques.

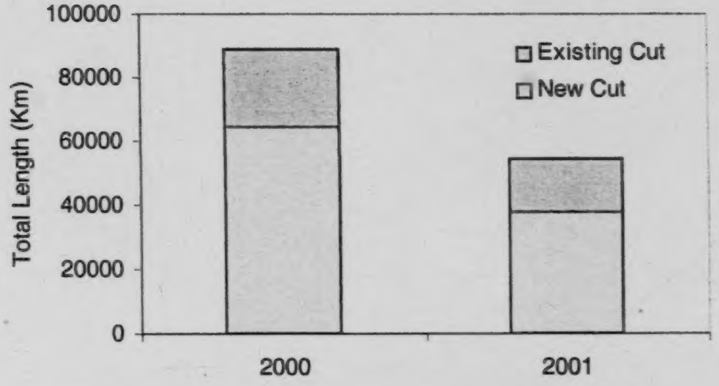

Figure 3. Total length of seismic lines cut for two years (2000 and 2001) divided by cut type. Existing cut entails re-clearing an existing seismic lines of any type. New cut is clearing standing forest and complying with current guidelines. Data from the Canadian Association of Geophysical Contractors (2002).

Appendix 3.1. Attributes of conventional (CON) and low impact (LIS) seismic lines and attributes of the surrounding stand for each site sampled (2002).

Type	Site #[1]	Twp-Rng-Mer	UTM Easting[2]	UTM Northing	Line Age	Ave. Width	Orientation	Stand Origin[3]	AVI Stand Type[4]
CON	142-1	69-11-4	458529.00	6092364.00	1993	9	N	1930	D19 Aw9 Bw1
CON	2054-1	69-11-4	459187.00	6093117.00	1993	8.95	E	1930	D19 Aw9 Bw1
CON	2307-1	69-11-4	457554.06	6096349.43	1989	8.6	E	1930	C17 Aw8 Bw1 Pb1
CON	2307-2	69-11-4	462034.14	6096129.36	1989	7	N	1930	C17 A10
CON	2307-3	69-11-4	463426.05	6096046.63	1989	6.4	N	1930	C17 Aw9 Pb1
CON	979-1	69-11-4	462960.86	6089696.82	1993	6	E	1910	B23 Aw8 Sw2
CON	980-1	69-11-4	456391.26	6093120.31	1993	6.5	E	1930	C19 Aw9 Pb1
CON	980-2	69-11-4	457046.70	6092120.30	1993	8.6	N	1930	B17 Aw7 Pb2 Bw1
CON	980-3	69-11-4	458122.00	6092120.30	1993	10	E	1930	D19 Aw9 Bw1
CON	981-1	69-11-4	456820.43	6095695.40	1993	5.3	E	1930	D17 Aw9 Bw1
CON	981-2	69-11-4	456822.41	6094709.65	1993	5.4	E	1920	C21 Aw5 W451
CON	981-3	69-11-4	456817.70	6092529.77	1993	7.4	N	1920	B22 Aw10
CON	11-1	67-11-4	459763.65	6071736.64	1993	8	E	1920	D21 Aw9 Pb1
CON	251-1	67-11-4	541065.00	6067846.00	1993	7.8	N	1940	C17 Aw7 Pb1
CON	92-1	66-12-4	449796.52	6068019.07	1990	9	E	1930	C19 Aw8 Pb2
CON	95-1	66-12-4	451681.63	6067171.64	1993	5.9	E	1930	C19 Aw9 Pb1
CON	95-2	66-12-4	448736.00	6067225.00	1993	6.4	E	1930	C19 Aw8 Pb1 Sw1
CON	97-1	66-12-4	449829.24	6067462.35	1993	7.9	E	1940	C17 Aw9 Pb1
CON	974-1	68-11-4	457576.34	6079059.46	1993	5.8	E	1930	D18 Aw9 Bw1
CON	155-1	68-10-4	468309.20	6079427.21	1989	6.9	E	1890	C25 Aw5 Pb3 Sw2
CON	NLB1-1	65-10-4	474652.74	6046553.19	1990	8	E	1940	C17 Aw7 Pb2 Bw1
CON	NLB2-1	65-10-4	474683.27	6047275.19	1990	8.6	N	1940	C17 Aw10
CON	NLB3-1	65-10-4	474976.02	6047491.67	1990	7	E	1940	C17 Aw9 Bw1
CON	6714-1	66-26-4	313632.63	6062535.64	1992	7.7	E	1930	C22 A8 Sw2
CON	6665-1	67-25-4	326958.02	6077988.51	1992	6.2	NW Diag	1910	B24 Aw7 Bw2 Sw1
CON	6665-2	67-25-4	324301.96	6080938.05	1992	5.2	NW Diag	1920	C22 Aw9 Sw1

Appendix 3.1 (continued). Attributes of conventional (CON) and low impact (LIS) seismic lines and attributes of the surrounding stand for each site sampled.

Type	Site #[1]	Twp-Rng-Mer	UTM Easting[2]	UTM Northing	Line Age	Ave. Width	Orientation	Stand Origin[3]	AVI Stand Type[4]
CON	6717-1	67-25-4	323503.80	6073972.14	1992	5.7	N	1910	C23 Aw5 Sw4 Bw1
CON	7839-1	68-26-4	310531.00	6082742.00	1992	7.1	E	1930	B21 Aw8 Bw2
CON	16201-1	71-21-4	359395.00	6110935.00	1989	8.7	N	1920	C24 Pb6 Aw3 Sw1
CON	18932-1	73-22-4	351287.00	6136131.00	1990	9.5	E	1920	C25 Aw7 Bw2 Sw1
LIS	385-1	67-11-4	456675.00	6070279.00	1996	4.2	E	1900	C20 Aw9 Pb1
LIS	31-1	68-12-4	452157.72	6087242.84	1996	6.0	E	1940	C17Aw8 Pb2
LIS	15-1	69-10-4	469388.07	6095215.52	1996	6.8	E	1910	C26 Aw5 Sw4 Pb1
LIS	22-1	69-12-4	450252.36	6093105.28	1996	6.0	N	1930	C19 Aw8 Pb1 Bw1
LIS	28-1	69-12-4	448889.70	6090443.43	1996	4.1	E	1940	C20 Aw9 Pb1
LIS	28-2	69-12-4	447744.00	6090274.00	1996	5.2	E	1940	C20 Aw9 Pb1
LIS	30-1	69-13-4	442975.16	6088491.68	1996	4.3	E	1940	C19 A9 Pb1
LIS	5721-1	70-11-4	459093.16	6098417.58	1993	5.5	E	1910	B26 Aw6 Sw2 Pb2
LIS	33-1	70-12-4	453204.00	6099676.00	1996	5.0	N	1930	C19 Aw10
LIS	5709-1	70-12-4	450313.37	6100990.85	1993	4.0	N	1920	C20 Aw8 Pb1 Sw1
LIS	5709-2	70-12-4	450285.96	6098660.03	1993	5.2	N	1930	C17 Aw7 Bw2 Pb1
LIS	5722-1	70-12-4	450549.76	6098593.48	1993	4.8	E	1920	C22 Aw7 Pb2 Sw1
LIS	15881-1	70-14-4	434178.00	6101776.00	1996	5.2	N	1940	C19 Aw10
LIS	43226-1	66-26-4	316908.77	6063656.15	1996	5.3	E	1930	B22 Aw8 Sw2
LIS	43226-2	66-26-4	317285.00	6063637.49	1996	7.5	E	1930	B22 Aw8 Sw2
LIS	43226-3	66-26-4	318018.13	6063607.75	1996	4.4	E	1940	D16 Aw9 Pb1
LIS	43226-4	66-26-4	318387.20	6063593.24	1996	5.2	E	1940	D16 Aw9 Pb1
LIS	44536-1	66-26-4	319258.00	6071309.17	1996	5.0	E	1920	B18 Aw9 Sw1
LIS	63884-1	66-26-4	315356.00	6068230.00	1997	4.7	N	1940	C17 Aw10
LIS	63884-2	66-26-4	315328.00	6067409.00	1997	5.3	N	1940	C17 Aw10
LIS	7996-1	68-26-4	312882.32	6085526.68	1992	5.2	E	1910	B24 Aw7 Pb3
LIS	9268-1	68-25-4	327864.00	6084192.00	1995	5.7	NE Diag	1920	C23 Aw9 Pb1

Appendix 3.1 (continued). Attributes of conventional (CON) and low impact (LIS) seismic lines and attributes of the surrounding stand for each site sampled.

Type	Site #[1]	Twp-Rng-Mer	UTM Easting[2]	UTM Northing	Line Age	Ave. Width	Orientation	Stand Origin[3]	AVI Stand Type[4]
LIS	9270-1	68-25-4	324036.85	6087736.91	1995	6.0	NE Diag	1920	C21 Aw10
LIS	9270-2	68-25-4	324583.00	6088082.00	1995	5.3	NE Diag	1920	C21 Aw10
LIS	9270-3	68-25-4	325708.87	6088751.83	1995	6.0	E	1920	C21 Aw9 Pb1
LIS	9278-1	68-25-4	321685.00	6081788.00	1995	6.3	E	1920	C22 Aw10
LIS	9279-1	68-25-4	325487.00	6086830.00	1995	5.5	N	1920	C20 Aw9 Pj1
LIS	9279-2	68-25-4	325510.00	6087420.00	1995	5.2	N	1920	C21 Aw10
LIS	46551-1	73-22-4	354457.41	6136497.87	1996	6.0	NE Diag	1930	B19 Aw7 Sw2 Pb1
LIS	46551-2	73-22-4	353426.00	6135431.00	1996	5.3	NE Diag	1920	C23 Aw8 Pb1 Sw1
LIS	46551-3	73-22-4	352953.00	6134973.00	1996	4.7	NE Diag	1920	C24 Aw9 Sw1

[1] Site# is a combination between the line# from the digital seismic line database and the site replicate number along the line.

[2] UTM Zone 12, NAD27 Datum

[3] Stand Origin is the decade in which the stand last burned.

[4] AVI stand type is a combination between canopy closure (class), canopy tree height (m) and canopy species composition (tree species and proportion of stems).

Canopy closure (% of ground covered by canopy): A = 6-30%, B = 31-50%, C = 51-70%, D = 71-100%

Species: Aw = trembling aspen, Pb = balsam poplar, Bw = paper birch, Sw = white spruce, Pj = jack pine

Appendix 3.2. Attributes of the seismic lines and the surrounding stand for each site with tree cores sampled (taken in 2001).

Line Type	Site #[1]	# Trees Cored	Twp-Rng-Mer	UTM Easting[2]	UTM Northing	Line Age	Orientation	Ave. Width	Stand Origin[3]	AVI Stand Type[4]
CON	16200-2	13	71-21-4	358041	6112414	1990	N	7.5	1920	C20 AW6 PB4 SW1
CON	16200-3	18	71-21-4	358451	6114653	1990	N	7.5	1900	A26 Aw8 Pb1
CON	16201-1	3	71-21-4	359381	6110748	1990	N	8.0	1920	C24 PB6 AW3 SW1
CON	16201-2	20	71-21-4	359445	6112644	1990	N	8.0	1920	C22 AW6 PB4
CON	16751-1	11	70-25-4	322036	6103362	1990	N	8.8	1920	C21 AW6 SW2 PJ1 PB1
CON	16751-2	12	70-25-4	322028	6102873	1990	N	8.8	1920	C23 AW7 SW3
CON	16898-1	15	71-25-4	324279	6114675	1992	N	7.0	1900	C24 AW10
CON	17777-1	15	73-22-4	354285	6135976	1990	E	8.7	1920	C12 AW9 PB1
CON	44888-1	17	71-21-4	357753	6109844	1993	N	6.5	1920	C23 AW7 PB2 SW1
LIS	10-1	18	69-11-4	462139	6094556	1996	NE Diag	6.6	1930	C19 AW10
LIS	13-2	11	69-12-4	449609	6093218	1996	E	5.5	1930	C24 AW8 BW1 SW1
LIS	22-1	19	69-12-4	450250	6093064	1996	N	5.5	1930	D21 AW9 PB1
LIS	29-1	7	69-13-4	443007	6089912	1996	E	4.7	1920	C23 Aw6 PB4
LIS	29-2	4	69-13-4	443418	6089925	1996	E	4.7	1930	C22 AW8 PB2
LIS	29-3	14	69-13-4	442199	6089873	1996	E	4.7	1920	C23 AW8 PB2
LIS	30-1	1	69-13-4	444163	6088480	1996	E	5	1930	C22 AW9 PB1
LIS	43515-1	22	73-22-4	353127	6135119	1996	NE Diag	4	1920	C24 AW 10
LIS	43515-2	18	73-22-4	353848	6135867	1996	NE Diag	4	1920	C21 AW9 PB1
LIS	43515-3	21	73-22-4	353486	6135489	1996	NE Diag	5	1920	C23 AW8 SW2
LIS	43515-4	17	73-22-4	354390	6136428	1996	NE Diag	6	1930	B19 AW7 SW2 PB1

[1] Site# is a combination between the line# from the digital seismic line database and the site replicate number along the line.

[2] UTM Zone13; NAD27 Projection

[3] Stand Origin is the decade in which the stand last burned.

[4] AVI stand type is a combination between canopy closure (class), canopy tree height (m) and canopy species composition (tree species and proportion of stems).

Canopy closure (% of ground covered by canopy): A = 6-30%, B = 31-50%, C = 51-70%, D = 71-100%

Species: Aw = trembling aspen, Pb = balsam poplar, Bw = paper birch, Sw = white spruce, Pj = jack pine

Appendix 4.1. Attributes of each conventional and low impact seismic line sampled (2001) as well as the surrounding stand. Conventional seismic line sites are further divided by line age category. YNG, MED, OLD stand for young (after 1998), medium (between 1979 and 1988), and older (before 1979) aged seismic lines.

Line Age Category	Year Cut	Site #[1]	Twp-Rng-Mer	UTM Easting[2]	UTM Northing	Width (m)	Line Orientation	Stand Origin[3]	AVI Stand Type[4]
YNG	1996	43444-1	70-24-4	333864	6101856	8	N	1920	C22 Pb5 Aw5
YNG	1996	43444-2	70-24-4	333827	6100873	9	N	1910	C23 Aw9 Sw1
YNG	1993	44888-1	71-21-4	357753	6109844	6	N	1920	C23 Aw7 Pb2 Sw1
YNG	1992	16898-1	71-25-4	324279	6114675	7	N	1900	C24 Aw10
YNG	1990	16200-2	71-21-4	358041	6112414	6	N	1920	C20 Aw6 Pb4 Sw1
YNG	1990	16200-3	71-21-4	358451	6114653	10	N	1900	A26 Aw8 Pb1
YNG	1990	16201-1	71-21-4	359381	6110748	8	N	1920	C24 Pb6 Aw3 Sw1
YNG	1990	16201-2	71-21-4	359445	6112644	8	N	1920	C22 Aw6 Pb4
YNG	1990	16751-1	70-25-4	322036	6103362	11	N	1920	C21 Aw6 Sw2 Pj1 Pb1
YNG	1990	16751-2	70-25-4	322028	6102873	7	N	1920	C23 Aw7 Sw3
YNG	1990	17777-1	73-22-4	354285	6135976	9	W	1920	C12 Aw9 Pb1
MED	1983	16215-1	71-21-4	360610	6113762		NE Diag.	1910	C23 Aw9 Pb1
MED	1982	16236-1	71-20-4	369772	6114673	8	N	1910	C24 Aw9 Pb1
MED	1982	16236-2	71-20-4	369780	6114982	8	N	1910	B24 Aw6 Sw4
MED	1982	16653-2	70-25-4	329551	6102881	8	W	1890	B26 Aw6 Pb4
MED	1982	16653-3	70-25-4	328698	6102909	8	W	1890	B26 Aw5 Pb4 Sw1
MED	1982	16653-4	70-25-4	328861	6102901	8	W	1910	A24 Aw8 Pb2
MED	1982	16653-5	70-24-4	330533	6102669	9	W	1890	B26 Aw6 Pb4
MED	1982	16653-6	70-25-4	327645	6102944	12	W	1940	D20 Aw7 Pb3
OLD	1977	7571-1	66-26-4	316953	6065021	12	NE Diag.	1943	B17 Aw9 Sw1
OLD	1977	7571-2	66-26-4	316339	6064398	8	NE Diag.	1940	C17 Aw9 Pb1
OLD	1976	16227-5	70-24-4	331778	6102494	10	W	1940	C11 Bw6 Fb3 Sw1
OLD	1970	16221-1	71-21-4	359197	6110464		NE Diag.	1950	C12 Aw5 Bw3 Sw1
OLD	1967	16291-1	71-22-4	347734	6113626	8	N	1940	C20 Aw10

Appendix 4.1. (continued)

Line Age	Year Cut	Site #[1]	Twp-Rng-Mer	Easting[2]	Northing	Width (m)	Line Orientation	Origin[3]	AVI Stand Type[4]
OLD	1967	16315-1	72-23-4	342289	6120540	8	W	1880	C26 Aw4 Sw3 Pb2 Fb1
OLD	1967	16315-2	72-23-4	343146	6120485	8	W	1880	B26 Pb5 Sw3 Aw2
OLD	1967	16315-3	72-23-4	341396	6120494	9	W	1880	C26 Pb6 Aw4
OLD	1964	16318-1	72-23-4	340155	6126868	7	N	1880	C26 Aw5 Pb5
OLD	1964	16661-1	70-25-4	322436	6105660	9	W	1940	C20 Aw7 Pb3
OLD	1964	16661-2	70-25-4	321291	6105688	9	W	1940	C20 Aw7 Pb3
OLD	1964	16670-1	70-25-4	321861	6108719	9	W	1940	D20 Aw9 Pb1
LIS	1996	10-1	69-11-4	462139	6094556	8	NE Diag.	1930	C19 Aw10
LIS	1996	10-2	69-11-4	463235	6096117	6	NE Diag.	1934	C17 Aw9 Pb1
LIS	1996	13-1	69-12-4	449147	6093235	4	W	1930	C21 Aw7 Bw2 Sw1
LIS	1996	13-2	69-12-4	449609	6093218	7	W	1930	C24 Aw8 Bw1 Sw1
LIS	1996	22-1	69-12-4	450250	6093064	6	N	1930	D21 Aw9 Pb1
LIS	1996	29-1	69-13-4	443007	6089912	4	W	1920	C23 Aw6 PB4
LIS	1996	29-2	69-13-4	443418	6089925	4	W	1930	C22 Aw8 Pb2
LIS	1996	29-3	69-13-4	442199	6089873	5	W	1920	C23 Aw8 Pb2
LIS	1996	30-1	69-13-4	444163	6088480	5	W	1930	C22 Aw9 Pb1
LIS	1996	43515-1	73-22-4	353127	6135119	4	NE Diag.	1920	C24 Aw10
LIS	1996	43515-2	73-22-4	353848	6135867	4	NE Diag.	1920	C21 Aw9 Pb1
LIS	1996	43515-3	73-22-4	353486	6135489	5	NE Diag.	1920	C23 Aw8 Sw2
LIS	1996	43515-4	73-22-4	354390	6136428	6	NE Diag.	1930	B19 Aw7 Sw2 Pb1

[1] Site# is a combination between the line# from the digital seismic line database and the site replicate number along the line.

[2] UTM Zone 12, NAD27 Datum

[3] Stand Origin is the decade in which the stand last burned.

[4] AVI stand type is a combination between canopy closure (class), canopy tree height (m) and canopy species composition (tree species and proportion of stems).

Canopy closure (% of ground covered by canopy): A = 6-30%, B = 31-50%, C = 51-70%, D = 71-100%

Species: Aw = trembling aspen, Pb = balsam poplar, Bw = paper birch, Sw = white spruce, Pj = jack pine

Appendix 4.2. List of species recorded in this study.

Scientific Name	Common Name
Abies balsamea (L.) Mill.	Balsam Fir
Achillea millefolium L.	Common Yarrow
Achillea sibirica Ledeb.	Many-flowered Yarrow
Actaea rubra (Ait.) Willd.	Red and White Baneberry
Agropyron repens (L.) Beauv.	Quack Grass
Agropyron trachycaulum (Link) Malte	Slender Wheat Grass
Alnus crispa (Ait.) Pursh	Green Alder
Alnus tenufolia Nutt.	River Alder
Amelanchier alnifolia Nutt.	Saskatoon Berry
Apocynum androsaemifolium L.	Spreading Dogbane
Aralia nudicaulis L.	Wild Sarsasparilla
Arnica chamissonis Less.	Leafy Arnica
Aster ciliolatus Lindl.	Lindley's Aster
Aster conspicuus Lindl.	Showy Aster
Betula occidentalis Hook.	Water Birch
Betula papyifera Marsh.	Paper Birch, White Birch
Bromus ciliatus L.	Fringed Brome
Calamagrostis canadensis (Michx.) Beauv.	Bluejoint or Marsh Reed Grass
Caltha palustris L.	Marsh Marigold
Carex spp.	Sedge
Cerastium nutans Raf.	Nodding Chickweed
Circaea alpina L.	Enchanter's Nightshade
Cirsium arvense (L.) Scop.	Canada Thistle
Clematis spp.	Purple Clematis
Cornus canadensis L.	Bunchberry
Cornus stolonifera Michx.	Red Oiser Dogwood
Corylus cornuta Marsh.	Beaked Hazelnut
Delphinium glaucum S. Wats.	Tall Larkspur
Disporum trachycarpum (S. Wats.) B. & H.	Fairy-bells
Elymus innovatus Beal	Hairy Wild Rye
Epilobium angustifolium L.	Fireweed
Equisetum arvense L.	Common or Field Horsetail
Equisetum pratense Ehrh.	Meadow Horsetail
Equisetum sylvaticum L.	Woodland Horsetail
Erysimum cheiranthoides L.	Wormseed Mustard
Festuca rubra L.	Red Fescue
Fragaria vesca L.	Woodland Strawberry

Appendix 4.2. (continued)

Fragaria virginiana Duchesne	Wild Strawberry
Galium boreale L.	Northern Bedstraw
Galium triflorum Michx.	Sweet-scented Bedstraw
Geocaulon lividum (Richards.) Fern.	Bastard Toad-flax
Geum aleppicum Jacq.	Yellow Avens
Geum macrophyllum Willd.	Yellow Avens
Geum rivale L.	Purple or Water Avens
Gymnocarpium dryopteris (L.) Newm.	Oak Fern
Habenaria obtusata (Pursh) Richards.	Blunt-leaved Orchid
Halenia deflexa (Sm.) Griseb.	Spurred Gentian
Heracleum lanatum Michx.	Cow Parsnip
Hieracium umbellatum L.	Narrow-leaved Hawkweed
Hylcomium splendens	Stair-step Moss
Koeleria cristata (L.) Pers.	June Grass
Lathyrus ochroleucus Hook.	Creamy Peavine
Lathyrus venosus Muhl.	Purple Peavine
Ledum groenlandicum Oeder	Labrador Tea
Lichen spp.	Lichen
Linnaea borealis L.	Twin-flower
Lonicera dioica L.	Twining Honeysuckle
Lonicera involucrata (Richards.) Banks	Bracted Honeysuckle
Lonicera villosa (Michx.) R. & S.	Fly Honeysuckle
Lophozia ventricosa	Leafy Liverwort
Lycopodium annotium L.	Stiff Club-moss
Lycopodium obscurum L.	Tree Club-moss
Maianthemum canadense Desf.	Wild Lily-of-the-valley
Mertensia paniculata (Ait.) G. Don	Tall Mertensia
Mitella nuda L.	Bishop's Cap or Mitrewort
Moneses uniflora (L.) A. Gray	One-flowered Wintergreen
Orthilia secunda L.	One Sided Wintergreen
Peltigera spp.	Leaf Lichen
Petasites palmatus (Ait.) A. Gray	Palmate-leaved Coltsfoot
Phleum pratense L.	Timothy
Picea glauca (Moench) Voss	White Spruce
Plantago major L.	Common Plantain
Pleurozium schreberi	Red-stemmed Feather Moss
Poa pratensis L.	Kentucky Bluegrass
Polytrichum piliferum	Awned Hair-cap

Appendix 4.2. (continued)

Polytrichum strictum	Slender Hair-cap
Populus balsamifera L.	Balsam Poplar
Populus tremuloides Michx.	Trembling Aspen
Potentilla norvegica L.	Rough Cinquefoil
Prunus pensylvanica L.f.	Pin Cherry
Prunus virginiana L.	Choke Cherry
Ptilium crista-castrensis	Knight's Plume
Pyrola asarifolia Michx.	Common Pink Wintergreen
Pyrola virens Schweigg.	Greenish-flowered Wintergreen
Ranunculus acris L.	Tall Buttercup
Ranunculus lapponicus L.	Lapland Buttercup
Rhinanthus borealis L.	Yellow Rattle
Ribes glandulosum Grauer	Skunk Currant
Ribes hudsonianum Richards.	Wild Black Currant
Ribes lacustre (Pers.) Poir.	Bristly Black Currant
Ribes oxyacanthoides L.	Wild Gooseberry
Ribes triste Pall.	Wild Red Currant
Rosa spp. Lindl.	Prickly or Common Wild Rose
Rubus idaeus L.	Wild Red Raspberry
Rubus pubescens Raf.	Dewberry, Running Raspberry
Salix spp.	Willow
Schizachne purpurascens (Torr.) Swallen	False Melic
Shepherdia canadensis (L.) Nutt.	Canadian Buffalo-berry
Smilacina stellata (L.) Desf.	Star-flowered Soloman's-seal
Solidago canadensis L.	Canada Goldenrod
Sonchus arvensis L.	Perennial Sow Thistle
Stellaria longifolia Muhl.	Common Chickweed
Symphoricarpos albus (L.) Blake	Snowberry
Symphoricarpos occidentalis Hook.	Buckbrush or Wolfberry
Taraxacum officinale Weber	Common Dandelion
Trientalis borealis Raf.	Northern Star Flower
Trifolium hybridum L.	Alsike Clover
Urtica dioica L.	Stinging Nettle
Vaccinium caepitosum Michx.	Dwarf Elderberry
Vaccinium myrtilloides Michx.	Blueberry
Vaccinium vitis-idaea L.	Bog Cranberry or Cow-berry
Viburnum edule (Michx.) Raf.	Low-bush Cranberry
Vicia americana Muhl.	Wild Vetch

Appendix 4.2. (continued)	
Viola adunca J.E. Smith	Early Blue Violet
Viola canadensis Greene	Western Canada Violet
Viola nephrophila Greene	Bog Violet
Viola renifolia A. Gray	Kidney Leaved Violet